

SCIENTIFIC NOTE

Human brain wave activity during exposure to radiofrequency field emissions from mobile phones

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Abstract

The aim of this study was to determine whether there is an effect of mobile phone electromagnetic field emissions on the human electroencephalograph (EEG). EEG recordings from ten awake subjects were taken during exposure to radiofrequency (RF) emissions from a mobile phone positioned behind the head. Two experimental trials were conducted. In the first trial, RF exposures were generated by a GSM mobile phone with the speaker disabled and configured to transmit at full-radiated power. During the second trial, exposures were generated by a non-modified GSM mobile phone in active *standby mode*. For each trial, subjects were exposed in five minute intervals to a randomized, interrupted sequence of five active and five sham exposures. The experiment was conducted under single-blind conditions. The average EEG band power in active exposure recordings was compared to corresponding sham recordings. Statistical tests indicated significant difference in the *full-power mode* trial within the EEG alpha (8–13 Hz) and beta (13–32 Hz) bands. A subsequent statistical analysis of median spectral power in discrete EEG rhythms revealed significant differences in 7 of the 32 distinct frequencies overall. In conclusion, the results of this study lend support to EEG effects from mobile phones activated in talk-mode.

Key words EEG, mobile phone, radiofrequency (RF), electromagnetic field (EMF), brain waves

Introduction

Mobile phones are now a part of everyday life for hundreds of millions of people around the world. Nonetheless, there is some public and scientific concern that usage of mobile phones may have as yet undetermined health implications.

In an attempt to address these concerns, researchers have utilized electroencephalographic (EEG) recordings to determine whether radiofrequency (RF) emissions from mobile phones influence human brain wave activity. These particular studies can vary in type depending on subject tasks or conditions during recordings. Such conditions have required subjects to be asleep^{1,2}, or awake and seated with eyes either open or closed^{3,4}. While other investigations have required subjects to participate in a memory task whilst under exposure to mobile phone RF emissions^{5,6}.

Amongst studies where subjects were required to be awake and seated, the reported results have been inconsistent. In one investigation, Reiser, et al.³ exposed 36

subjects (18 males; 18 females) to a mobile phone's RF emissions for a duration of 15 minutes. The mobile phone had a carrier frequency of 902.4 MHz, which was modulated at 217 Hz. The phone was programmed to transmit at 8 W, and was placed at a distance of 40 cm from the rear of the head during the experiment. Results of the study indicated power increases in the EEG frequency bands of 9.75 Hz – 12.5 Hz (Alpha 2), 12.75 – 18.5 Hz (Beta 1) and 18.75 – 35 Hz (Beta 2). The increases occurred approximately 15 minutes after exposure ceased.

In another investigation of the same type, Rösche and Mann⁷ found no alteration in the awake, closed eyed condition EEG of 34 men when exposed to a 900 MHz field pulsed with a rate of 217 Hz. A statistical analysis was conducted for the spectral power densities in the EEG frequency bands 1 – 3.5 Hz (Delta), 3.5 – 7.5 Hz (Theta), 7.5 – 12.5 Hz (Alpha), and 12.5 – 18 Hz (Beta). The source of exposure was a GSM (Global System for Mobile Communication) mobile phone with an aerial peak power of 8 W. The duration of exposure lasted nearly 3.5 minutes and was placed 40 cm from the 'vertex'.

Although the two investigations described above can be somewhat compared due to their similar parameters this is not yet typical of this developing field. Greater combination and replication of basic common test variables such as exposure levels, duration of exposure, and source positioning, is necessary before adequate conjecture can be drawn.

This paper will present a pilot study where the awake

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EEG was recorded and subjects were required to be seated still with eyes closed whilst being exposed to RF emissions from mobile phones in *full-power* and *standby* modes.

Materials and methods

Sources of exposure

This investigation was conducted in two trials using two different mobile phones in different power output modes. In the first trial, RF exposures were generated by a modified Nokia 6110 mobile phone, which had its speaker disabled to eliminate possible auditory cues. The phone was configured to be enabled via control software to transmit at a nominal average power of 250 mW (2 W peak output) with a 900 MHz carrier modulated at 217 Hz. Due to this configuration, standby mode exposures could not be activated and any power variability caused by GSM power control modes such as discontinuous transmission (DTX)⁸ was removed. Thus only nominal full-radiated power was transmitted. In the second trial, standby mode exposures were generated by a standard Ericsson GH388 mobile phone. In this mode of operation, GSM mobile phones such as these have been found to emit low frequencies within 1-32 Hz⁹, which are within the range of the brain's normal EEG activity.

The Nokia 6110 phone was supplied by Telstra Research Laboratories*.

Subjects

Ten healthy subjects in total participated in this investigation. This included 5 men and 5 women with ages ranging from 18 to 30 years. All participants gave verbal consent that they were not on any medication in the recent month prior to the trial period.

Subject conditions

For each subject EEG electrodes were positioned at the Fp1 & Fp2, C3 & C4, O1 & O2 recording sites according to the 10/20 international standard¹⁰. To sustain good conductivity during trials, the electrodes were checked for secure contact between all EEG recordings. The electrode leads were twisted as far as possible, as a measure against the potential for RF pickup, and then fed into a differential amplifier (Mindset EEG acquisition unit).

A mobile phone was placed horizontally behind the subject's head with the antenna positioned 2 cm away from the occipital region as shown in Figure 1.

During the EEG recordings subjects were required to have their eyes closed, and to be awake whilst sitting still in a comfortable back supported chair. Subjects were able to maintain this position in a relaxed state.

Trial procedure

Two trials were conducted. During the first trial, the real-time EEG of each subject was recorded for a total duration of 50 minutes in a silent room. This consisted of

ten 5-minute EEG recordings of which five were recorded whilst the Nokia mobile phone was in *full-power mode* and positioned at the rear of the head (Figure 1). The remaining five recordings were sham exposure recordings. During the sham exposure recordings the mobile phone was switched off completely though remained in position. For each subject, the five exposure and five sham EEG recordings were randomized such that participants were not aware of the state of exposure of the mobile phone. After every 5-minute EEG recording subjects took a 10-15 minute break. During the second trial of this investigation, the Ericsson mobile phone in *standby mode* was used as the source of exposure. Apart from this, the procedure of the second trial was identical the first. The same ten subjects participated in both trials.

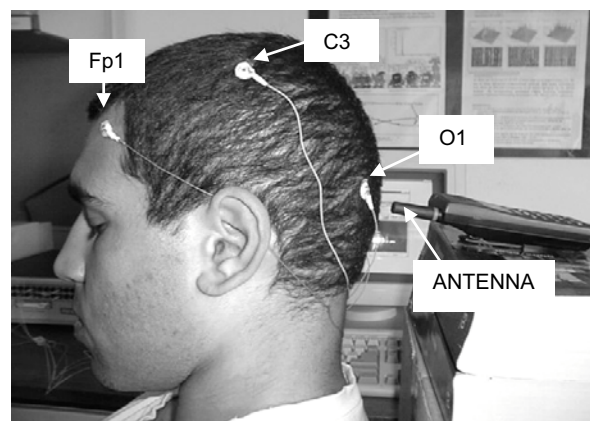


Figure 1. Photograph of phone/antenna positioning with respect to the head and electrode recording sites.

Analysis and results

All EEG data collected during the two trials was realized in the frequency domain between 1 - 32 Hz using the Mindset EEG processing software (Wavelab). For each subject, the EEG data obtained under both sham and exposure conditions was then classified into the four clinically significant EEG bands, namely, delta (1 – 4 Hz), theta (4 – 8 Hz), alpha (8 – 13 Hz), and beta (13 – 32 Hz). The five sham recordings as well as the five exposure recordings (obtained from each subject in both trials) was then averaged within the EEG bands so that there was one set of sham mean data and one set of exposure mean data per recording site. Hence, as EEG data was simultaneously accumulated from three recording sites (Figure 1), there were three sets of sham/exposure EEG data to be analyzed for each subject in the full-power mode and standby mode trials.

A paired t-test was conducted to statistically analyze whether there were any significant differences between the resultant averaged power in the sham and exposure data sets. The results of the t-test are outlined in Tables 1 & 2 where p-values are considered significant at less than 0.05.

In addition to determining the statistical levels of difference between the mean sham and exposure EEG

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Recording Site	Full-power mode trial							
	Delta		Theta		Alpha		Beta	
	95% CI (μ V)	p-value	95% CI (μ V)	p-value	95% CI (μ V)	p-value	95% CI (μ V)	p-value
Frontal	-2.3, 7.0	0.281	-1.3, 3.8	0.289	-0.5, 1.8	0.264	-0.6, 1.1	0.519
Central	-1.0, 9.0	0.106	-1.9, 7.0	0.232	0.1, 3.7	<i>0.038</i>	0.03, 1.9	<i>0.045</i>
Occipital	-0.4, 11.3	0.065	-1.3, 8.8	0.13	-0.1, 5.3	0.06	0.01, 3.0	<i>0.049</i>

Table 1. T-test results indicated for the full-power mode trial where averaged sham exposure recordings were compared to averaged exposure test recordings in the delta, theta, alpha, and beta EEG bands. Statistical levels were considered significant at p-values < 0.05 (shown in italic).

Recording Site	Standby mode trial							
	Delta		Theta		Alpha		Beta	
	95% CI (μ V)	p-value	95% CI (μ V)	p-value	95% CI (μ V)	p-value	95% CI (μ V)	p-value
Frontal	-2.1, 0.4	0.166	-0.6, 0.2	0.320	-0.4, 0.1	0.337	-0.3, 0.1	0.332
Central	-1.5, 2.3	0.621	-0.8, 2.3	0.287	-0.3, 0.6	0.442	-0.2, 0.3	0.775
Occipital	-0.5, 1.7	0.215	-1.0, 0.9	0.916	-1.2, 1.2	0.959	-0.2, 0.3	0.583

Table 2. T-test results indicated for the standby mode trial where averaged sham exposure recordings were compared to averaged exposure test recordings in the delta, theta, alpha, and beta EEG bands. Statistical levels were considered significant at p-values < 0.05.

recordings within the delta, theta, alpha, and beta bands, further analysis was undertaken to observe whether there were any trends in the number of subjects indicating a decrease or increase in EEG power due to the full-power mode and standby mode exposures. To do this, for each subject, the median sham data minus the median exposure data was calculated for each discrete EEG rhythm between 1 – 32 Hz. As the exposure data was subtracted from the sham data, a negative result was labeled an 'increase' in EEG power, a positive result was labeled a 'decrease' in EEG power, and a null result was labeled a 'no difference' in EEG power. Figures 2 & 3 indicate the percentage of subjects that indicated an EEG power decrease in each EEG rhythm as well as show the corresponding distributions of the frontal, central, and occipital recording regions of interest.

A subsequent paired t-test was conducted on the overall median paired sample in EEG rhythms to assess the significance of difference where a very high percentage (80%+) of subjects indicated a resultant decrease in EEG spectral power. Rhythms where a low percentage (20% or less) of subjects indicated a resultant decrease were also of interest as this was equivalent to a high percentage of subjects indicating an increase in EEG power. The results of the t-test are indicated in Tables 3 & 4 for the full-power mode and standby-mode trials respectively. The tables indicate the EEG rhythms and corresponding recording sites at which the high tendency decreases and increases occurred as well as the resultant p-values (considered significant at $p < 0.05$).

In addition to the full-power and standby mode trials, electrode lead susceptibility to RF emissions from a Nokia 6110 mobile phone in active *talk mode* was tested. In this

trial two EEG electrodes were positioned 10 cm apart on an adults thigh, perpendicular to the length of the leg. The subject was seated still with the thigh horizontally at rest to prevent possible pickup of biopotential activity caused by movement. As in the full-power and standby mode trials, five 5-minute differential sham exposure and exposure recordings were logged by the Mindset EEG acquisition unit. The exposure recordings required the mobile phone to be suspended 2 cm above the thigh, at the mid-point between the two electrodes. A paired t-test was conducted to compare the average spectral sham exposure and exposure data in the EEG delta (1 – 4 Hz), theta (4 – 8 Hz), alpha (8 – 13 Hz), and beta (13 – 32 Hz) bands. Resultant statistical levels in all four bands indicated p-values greater than 0.2 indicating no significant difference between the mean sham exposure and exposure data (p-values considered significant at $p < 0.05$).

Discussion

Results of the full-power mode trial where the average spectral power in the delta, theta, alpha, and beta EEG bands were considered (Tables 1 & 2) indicate that there were statistically significant levels of difference between the sham and exposure tests conducted. These results can be seen in Table 1 (shown in italic) in the alpha and beta bands from the central recording site ($p = 0.038$ and $p = 0.045$ respectively) and in the beta band from the occipital region ($p = 0.049$). The 95% confidence intervals of these significant results suggest that there was a decrease in mean EEG potential between as low as 0.01 μ V to 3.7 μ V during

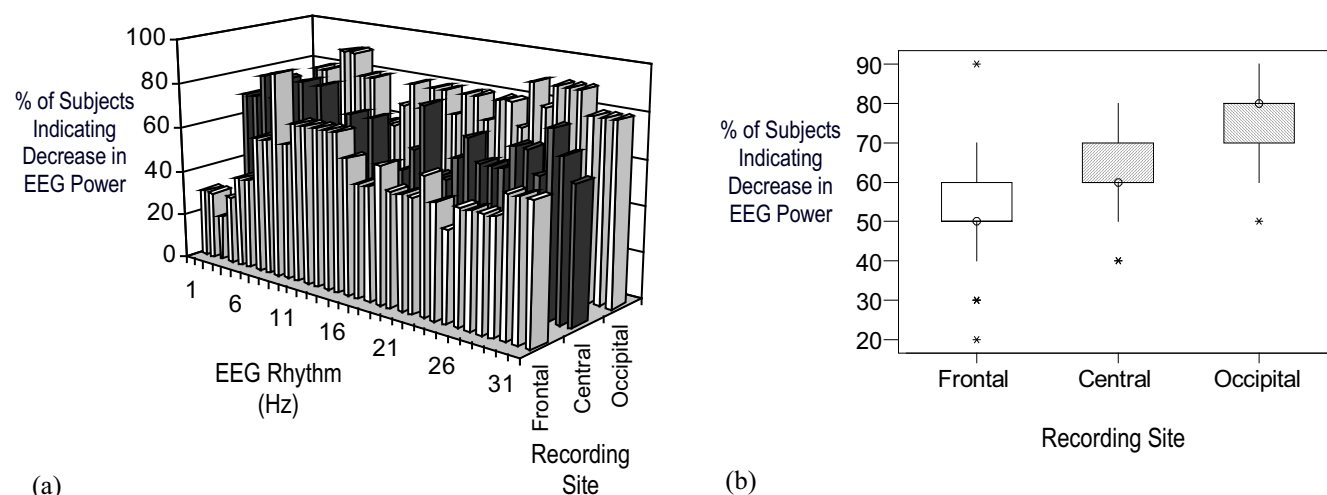


Figure 2. Full-power mode trial results: (a). For each subject, the median sham data minus the median exposure data was calculated for each discrete EEG rhythm between 1 – 32 Hz. Resultant decreases in EEG power were identified. The percentage of subjects indicating a decrease in EEG power are shown in each rhythm from the standard frontal, central, and occipital regions; (b). The corresponding distribution plots of Figure 2(a). The 'boxes' indicate where at least 50% of the distribution lie. The 'box-whiskers' and asterisks (data outliers) together indicate where at least 25% of the distribution lie. The circles indicate the median point of the distribution.

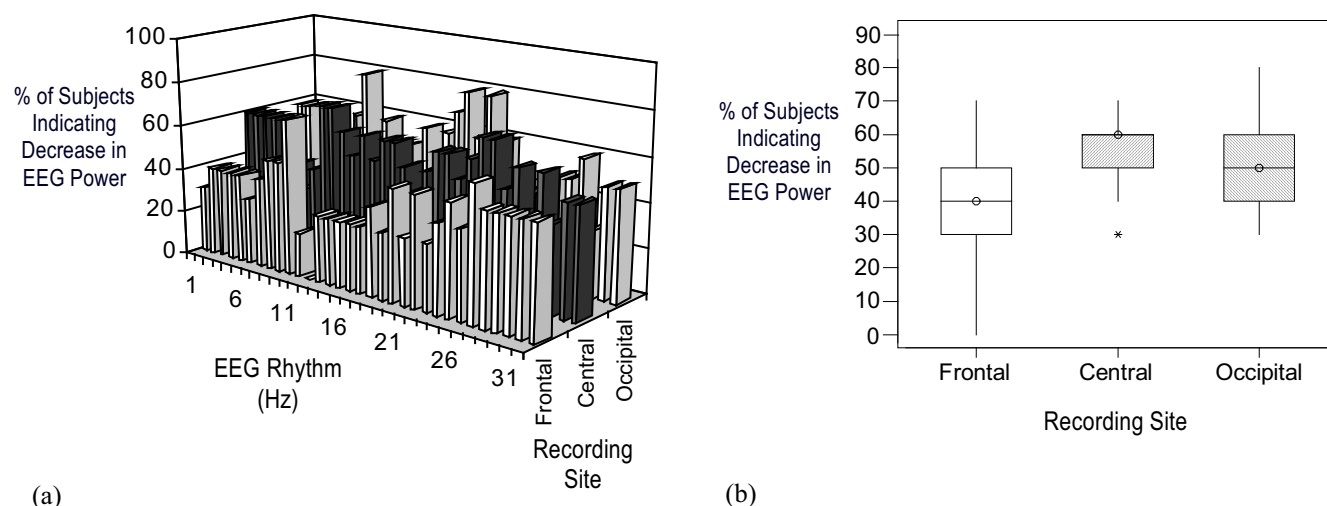


Figure 3. Standby mode trial results: (a). For each subject, the median sham data minus the median exposure data was calculated for each discrete EEG rhythm between 1 – 32 Hz. Resultant decreases in EEG power were identified. The percentage of subjects indicating a decrease in EEG power are shown in each rhythm from the standard frontal, central, and occipital regions; (b). The corresponding distribution plots of Figure 3(a). The 'boxes' indicate where at least 50% of the distribution lie. The 'box-whiskers' and asterisks (data outliers) together indicate where at least 25% of the distribution lie. The circles indicate the median point of the distribution.

the full-power mode exposure. Notably, there was no apparent alteration in EEG activity from the frontal region. This absence of change in frontal region activity coincides with reports made by Reiser, et al.³ where the active mobile phone source was also placed behind the subject's head. No statistically significant results are apparent in the standby mode trial (Table 2) over the delta, theta, alpha, and beta bands.

Also indicating no statistically significant levels in the four EEG bands of interest were the results of the electrode lead susceptibility trial where EEG electrode leads

(positioned on a subject's thigh) were exposed to mobile phone talk mode emissions. The results of this trial suggest that neither the GSM talk mode emissions nor the data acquisition equipment influenced the electrode leads during EEG recordings. These findings are in accordance with other investigators who also report negligible effects of mobile phone RF emissions on EEG electrode leads⁴.

Apart from analysis of average spectral power in the delta, theta, alpha, and beta EEG bands, analysis of sham and exposure median differences in discrete EEG rhythms were considered (Figures 2 & 3). Figure 2(a) indicates

Full-power mode trial				
EEG rhythm (Hz)	Rec. site	% of subjects indicating decrease	95% CI (μ V)	p-value
3	F	20	-3.1, 4.6	0.673
9	F	90	0.1, 0.6	0.009
3	C	80	-1.9,10.2	0.155
5	C	80	-1.3, 7.5	0.141
7	C	80	0.6, 5.0	0.020
9	C	80	0.5, 4.9	0.022
19	C	80	-0.1, 1.7	0.076
30	C	80	-0.1, 1.7	0.070
4	O	80	-0.9,10.3	0.089
5	O	80	-0.8, 9.7	0.087
7	O	90	0.5, 9.0	0.032
8	O	90	0.7, 8.7	0.026
9	O	80	0.9, 6.9	0.017
10	O	80	-0.4, 7.5	0.073
14	O	80	-0.3, 5.2	0.071
16	O	80	-0.2, 5.7	0.065
17	O	80	0.0, 5.3	0.050
19	O	80	0.0, 4.9	0.050
20	O	80	-0.4, 5.4	0.086
22	O	80	-0.1, 4.3	0.063
23	O	80	-0.1, 3.6	0.056
25	O	90	-0.1, 3.5	0.061
26	O	80	-0.2, 3.0	0.082
27	O	90	0.1, 2.6	0.034
28	O	90	-0.0, 2.4	0.055
29	O	90	-0.2, 2.4	0.078
30	O	80	-0.5, 2.7	0.151
31	O	80	-0.7, 2.4	0.248
32	O	80	-0.5, 1.8	0.231

Table 3. *T*-test results in the full-power mode trial following analysis of differences in sham and exposure median spectral power. Shown are the significant levels of cases where a high and low percentage of subjects indicated resultant decrease in EEG power. F = Frontal; C = Central; O = Occipital.

EEG rhythm (Hz)	Rec. site	Standby mode trial		p-value
		% of subjects indicating decrease	95% CI (μV)	
11	F	20	-0.8,0.03	0.069
12	F	0 [†]	-0.5,-0.1	<i>0.004</i>
9	C	80	-0.2, 5.1	0.062
19	C	80	-0.1, 0.9	0.090
21	C	80	-0.1, 0.6	0.093

Table 4. *T*-test results in the standby mode trial following analysis of differences in sham and exposure median spectral power. Shown are the significant levels of cases where a high and low percentage of subjects indicated resultant decrease in EEG power. F = Frontal; C = Central; O = Occipital; [†]0% decrease though 90% of subjects indicating increase in EEG power due to one subject showing a 'no difference' between sham and exposure data.

results of this analysis for the full-power mode trial. Observation of the figure shows a particularly high percentage (80%+) of subjects indicating a decrease in EEG power over most of the occipital EEG rhythms. Furthermore, the occipital results can be seen to be evidently higher than the frontal and central region results. The distribution plots (box graphs) of Figure 2(b) outline this particular observation. The occipital distribution in Figure 2(b) demonstrates that in at least 75% of the 32 EEG rhythms analyzed 70% – 90% of subjects indicated a decrease in EEG power. Neglecting data outliers, approximately 25% of the corresponding central and 75% of the frontal distributions lie below the occipital plot. Consequently, the full-power mode distributions of Figure 2(b) appear to steadily decline from occipital (highest), to central, to frontal (lowest). It is speculated that this may occur due to the mobile phone exposure being applied from the rear of the head (closer to the occipital region and furthest from the frontal region).

Unlike the full-power mode trial results described, the corresponding standby mode graphs of Figure 3 do not appear to demonstrate any outstanding characteristics. Nonetheless, at 9 Hz, 19 Hz, and 21 Hz a high percentage of subjects (80%+) indicated a decrease in EEG spectral power.

Tables 3 and 4 indicate all high and low percentages of subjects indicating a decrease in EEG power for the full-power mode and standby mode trials respectively. As outlined previously, a low percentage (20% or less) in number of subjects indicating a decrease in EEG power is equivalent to a high percentage of subjects indicating an increase in EEG power. Thus, it can be seen that a high percentage of subjects indicated an increase in EEG power at 3 Hz in the full-power mode trial (Table 3) and at 11 Hz and 12 Hz in the standby mode trial (Table 4). In consideration, at 12 Hz the difference in sham and exposure median spectral power was found to be statistically significant ($p = 0.004$; Frontal region; CI: -0.5, -0.1) as shown in *italic* in Table 4.

Significant p -values in the full-power mode trial for a high percentage of subjects indicating a decrease in EEG power were also identified (shown *italic* in Table 3). They occurred at 9 Hz in the frontal region ($p = 0.009$, CI: 0.1, 0.6), in the central region at 7 Hz ($p = 0.020$, CI: 0.6, 5.0) and 9 Hz ($p = 0.022$, CI: 0.5, 4.9), and in the occipital region at 7 Hz ($p = 0.032$, CI: 0.5, 9.0), 8 Hz ($p = 0.026$, CI: 0.7, 8.7), 9 Hz ($p = 0.017$, CI: 0.9, 6.9), 17 Hz ($p = 0.05$, CI: 0.0, 5.3), 19 Hz ($p = 0.05$, CI: 0.0, 4.9), and 27 Hz ($p = 0.034$, CI: 0.1, 2.6). Of particular interest amongst these significant levels are 7 Hz (Theta rhythm), 8 Hz (alpha rhythm), and 9 Hz (alpha rhythm) as these frequencies are in succession and therefore are less likely to have occurred by statistical chance. Furthermore, these frequencies have relatively substantial 95% confidence intervals ranging minimally from 0.5 μ V to at least 6.9 μ V. It is also very interesting to note that the EEG rhythms 7 Hz and 9 Hz indicate statistically significant values (for decrease in EEG power) in both the

occipital and central recording sites. Moreover, statistically significant levels are evident at 9 Hz in all three recording sites.

Conclusion

This study suggests that a change in human brain wave activity occurred in the alpha (8 – 13 Hz) and beta (13 – 32 Hz) EEG bands during exposure to a GSM mobile phone configured to transmit at full-radiated power. A corresponding statistical analysis in EEG bands during exposure to a GSM mobile phone in standby mode did not indicate any significant levels of change. Aside from this analysis in EEG bands, median differences between sham and exposure EEG data in each discrete EEG rhythm (from 1 - 32 Hz) were observed. Results of the full-power mode trial showed that in at least 75% of the 32 EEG rhythms analyzed 70% – 90% of subjects indicated a decrease in EEG power. This again suggested that the full-radiated power might be responsible for alteration in the normal (sham exposure) EEG recordings. No predominant characteristics were apparent under standby mode conditions. A subsequent statistical analysis was conducted for the cases where a very high percentage of subjects indicated a resultant decrease or increase in EEG power. Results of particular interest were consecutive findings at 7 Hz (Theta rhythm), 8 Hz (Alpha rhythm), and 9 Hz (Alpha rhythm) that indicated statistically significant decrease in EEG power from the occipital region in the full-power mode trial. In addition, a decrease in EEG power at 7 Hz and 9 Hz were found to be statistically significant in both the occipital and central recording sites. Moreover, in the full-power mode trial, statistically significant levels were apparent at 9 Hz from all three recording sites (frontal, central, and occipital).

In conclusion, from the perspective that far greater statistical significance and notable characteristics were evident in the full – power mode trial than in the standby mode trial (almost negligible significance), it is speculated that the field characteristics of the full-power mode exposure may influence human brain activity. However, this is a pilot study and should be considered as such.

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