# Statistical Analysis of the Human EEG during RF Exposure from Mobile Phones: An Alternative Method to Analysis of the EEG in Frequency Bands

Howard D'Costa[1, 2], Irena Cosic[1, 2]

[1]School of Electrical & Computer Engineering, RMIT University, Melbourne, Australia
[2]Australian Centre for Radiofrequency Bioeffects Research

**Abstract.** This paper aims to describe a novel statistical approach to analysing the effects of radiofrequency (RF) exposures from mobile phones on the human EEG. In addition, the paper describes two limitations that may be encountered when using statistical methods to analyse the EEG in its *frequency bands*. The proposed method of analysis which is based on measures of central tendency introduces an approach whereby the recorded body of EEG data collected during trials can be effectively interpreted for spectral analysis at a higher resolution across the EEG spectrum. It is believed that the proposed statistical approach may be also useful in other studies investigating the effects of alternate forms of involuntary stimulus on the human EEG, such as electrical stimulus, light, and sound.

## 1 Introduction

It is as yet undetermined whether mobile phone exposures can cause adverse health implications or changes in human brain function. In an attempt to address these concerns, researchers have utilised electroencephalographic (EEG) recordings to determine whether radiofrequency (RF) emissions from mobile phones influence human brain wave activity. A common approach to statistical analysis in these investigations, is to analyse the EEG in its generally classified frequency bands, namely delta (1-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), and beta (13-32 Hz) [1][2][3][4]. Nevertheless, amongst these studies there can be found slight variations in the EEG spectral ranges analysed. In a study by Hietanen et al.[5] EEG recordings were obtained from 19 participants during exposure in separate tests to five active mobile phones operating at either 900 MHz or 1800 MHz. The phones were positioned 1 cm from the left side of the head and generated a peak output power ranging from 1 - 2 W. With the exception of the delta region from one of the test phones statistical comparisons drawn between control and exposure trials indicated no significant changes in the EEG frequency bands 1.5 – 3.5 Hz (delta), 3.5 – 7.5 Hz (theta), 7.5 – 12.5 Hz (alpha), and 12.5 – 25 Hz (beta). In another investigation by Reiser et al. [6] 36 subjects were exposed 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

D'Costa H. and Cosic I. (2005).
Statistical Analysis of the Human EEG during RF Exposure from Mobile Phones: An Alternative Method to Analysis of the EEG in Frequency Bands.
In *Proceedings of the 1st International Workshop on Biosignal Processing and Classification*, pages 167-174
DOI: 10.5220/0001197301670174

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.

Although investigations in this area of study have until now concentrated on analysis of the EEG in its spectral bands, there is however significant limitations to this approach that should be considered. With respect to the utilisation of the EEG as basis to detect an external stimulus, these limitations primarily arise from the moderate spectral resolution analysis imposed by relatively wide ranges of the EEG frequency bands. As opposed to analysis of the EEG in spectral bands, alternate use of non-linear statistical methods have been produced by others in related electromagnetic field effect studies [6][7].

From an adapted analysis of our previous work (D'Costa et al. [8]), this paper aims to present a novel statistical approach to analysing the human EEG where all frequencies within the EEG spectrum can be analysed. In addition, the paper aims to describe and outline the limitations associated with statistical analysis of the EEG in its spectral bands.

## 2 Limitations of Analysis of the EEG in Frequency Bands

There are two evident limitations associated with statistically analysing the EEG in its frequency bands for the purpose of determining whether an external stimulus such as mobile phones affect human brain waves. These limitations may be described as follows:

1. Important data is potentially lost due to averaging in frequency bands when drawing comparisons between control and exposure EEG data sets. For example, the alpha EEG band spans over five distinct frequencies from 8 -13 Hz. In order to prepare this band for hypothesis testing the total EEG power across each of the five frequencies must be averaged to one value for both the exposure and control test recordings. For this reason it is arguable that an effect due exposure can occur in any one of the five frequencies though may be lost through averaging. The probability for this loss occurring is even more so for the beta band (>13 Hz) where up to 20 or more frequencies may be averaged.
2. Identification of potential changes in frequency ranges spanning across the EEG band divisions are not observable which may mask potential effects. For example if an alteration in the EEG due to an applied exposure existed over a range spanning from 5 – 9 Hz the effect may become impossible to observe as theta (4 – 8 Hz) and alpha (8 - 13 Hz) must be independently analysed.

An example of results for an analysis conducted in frequency bands is shown below in Table 1 (adopted from D'Costa et al. [8]). In this study ten participnats were exposed to a mobile phone operating at 900 MHz at nominal full-power (2 W peak output). The EEG was recorded from the frontal, central, and occipital regions of the head in a series of five control and five exposure tests. A paired t-test analysis was conducted to draw statistical comparisons between the averaged control and exposure

test recordings. The t-test results are indicated below for the four EEG frequency bands of interest analysed.

**Table 1.** Shows an example of results adopted from D'Costa et al.[8] for an analysis conducted in the EEG frequency bands delta (1-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), and beta (13-32 Hz). Statistical levels were considered significant at p-values < 0.05 (shown in italic)

| | Delta | | Theta | | Alpha | | Beta | |
|---|---|---|---|---|---|---|---|---|
| Recording Site | 95% CI (μV) | p-value | 95% CI (μV) | p-value | 95% CI (μV) | p-value | 95% CI (μV) | 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 | *0.038* | 0.03, 1.9 | *0.045* |
| Occipital | -0.4, 11.3 | 0.065 | -1.3, 8.8 | 0.13 | -0.1, 5.3 | 0.06 | 0.01, 3.0 | *0.049* |

It can be observed in table 1 above that the t-tests results indicated statistically significant differences in the alpha and beta bands (p-values < 0.05). However, in contrast and based on the limitations described above, it may also be shown that it is not possible to determine whether the mobile phone exposure produced a potential influence across or at particular frequency rhythms within the four EEG bands.

## 3 Proposed Analysis of the EEG

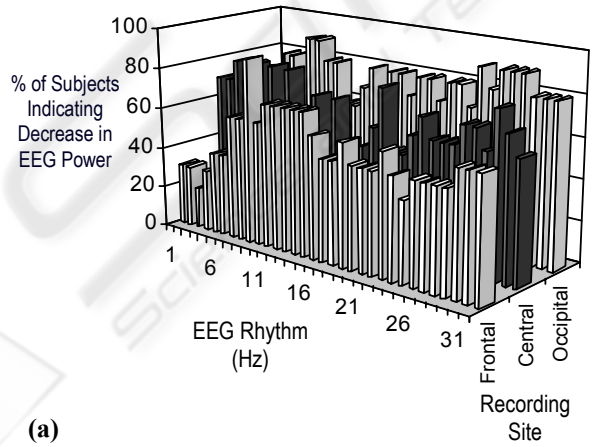
By employing existing statistical methods, this section describes a novel approach where all frequencies in the EEG spectrum are considered to investigate the effects of mobile phone RF exposures on human brain wave activity. The method of analysis is described in the following 3 stages given the basic case that four control EEG recordings are to be compared to four exposure EEG recordings acquired from a sample size of 10 participants (EEG spectral range is 1-32 Hz):

Step 1. From each of the four control and four exposure recordings 4 × 32 EEG power values (×10) are generated. For each participant, the median EEG power value of the four control recordings in each EEG frequency (from 1 -32 Hz) minus the corresponding median in the four exposure recordings is calculated. The resultant number of positive values or *decreases* in each EEG frequency is then identified over the entire sample. Table 2 below demonstrates a mock example of an output table generated for this step at the arbitrary rhythm of 7 Hz. In a similar manner, the number of negative values or *increases* may be alternatively chosen.

**Table 2.** Shown is an example of the paired sample of median values of the control and stimulus EEG recordings at 7 Hz. The median differences in EEG power and respective identified decreases in EEG can be observed. In this example 8 out of the 10 participants indicated a decrease in the median EEG power at 7 Hz

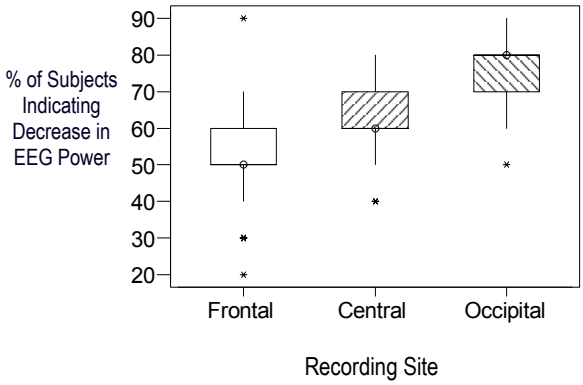
| Participant | Median value of control recordings at 7 Hz (μV) | Median value of stimulus recordings at 7 Hz (μV) | Median difference at 7 Hz (μV) | Noted decrease in EEG |
|---|---|---|---|---|
| **1** | 18 | 11 | 7 | x |
| **2** | 15 | 16 | -1 | |
| **3** | 25 | 20 | 5 | x |
| **4** | 14 | 16 | -2 | |
| **5** | 16 | 10 | 6 | x |
| **6** | 26 | 23 | 3 | x |
| **7** | 18 | 11 | 7 | x |
| **8** | 15 | 12 | 3 | x |
| **9** | 16 | 12 | 4 | x |
| **10** | 19 | 15 | 4 | x |

By observation of Table 2, it can be seen that up to 80% of the participants for example indicated a decrease in EEG power at 7 Hz. By repeating this process for all 32 frequencies a distribution of the percentage of subjects indicating a decrease in EEG power versus frequency may be generated. If EEG recordings were to be simultaneously acquired from multiple recording site locations on the head a 3D illustration of these distributions may be shown as given for example in Figure 1(a).




**(a)**

**Fig. 1.(a)** Shows an example of distributions of the percentage of subjects indicating a decrease in EEG power versus frequency as generated in step 1. As shown, distributions produced for simultaneous EEG recordings acquired over multiple recording site locations may be indicated. In this example three recording sites are considered over the frontal, central, and occipital regions of the head (example adopted from D'Costa et al.[8])

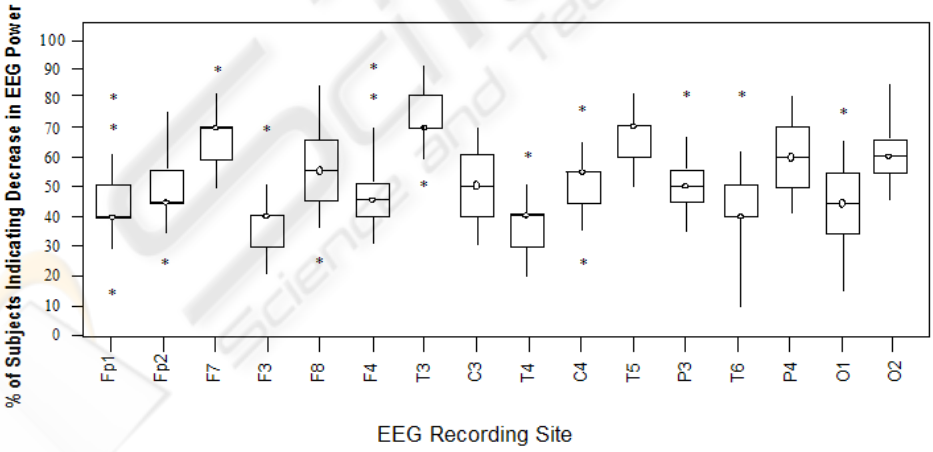



**(b)**

**Fig 1(b)** The corresponding distribution plots of figure 1(a) as generated for step 2. The 'boxes' indicate where at least 50% of the distribution lies. The 'box-whiskers' and asterisks (data outliers) together indicate where at least 25% of the distribution lie

Step 2. For further interpretation, the distributions generated in step 1 (Fig. 1(a)) are interpreted to standard *Box Diagram* plots as indicated in Figure 1(b). As per standard [10] the 'boxes' indicate where at least 50% of the distribution lies. The 'box-whiskers' and asterisks (data outliers) together indicate where at least 25% of the distribution lie.

Distribution plots for a larger number of recording regions may also be effectively shown as Figure 2 below indicates for a standard 16 -point EEG recorded array (10-20 International standard [11]).



Step 3. Lastly, with reference to step 1, a paired t-test analysis is conducted on the *median paired data sets* in each frequency where 75-100% of subjects indicate an increase or decrease in EEG power. Table 3 below demonstrates an example of an output table of results that may be generated for this step. The table can be observed to indicate 95% confidence intervals and corresponding p-values produced by the paired t-test analysis for each of the identified frequency rhythms. The p-values in this example are considered to be statistically significant for values less than 0.05 as indicated in italic *(example adopted from D'Costa et al.[8]).*
Larger data sets, such as in the case for a 16-point EEG analysis, may also be represented in this manner, or simplified to indicate the significant statistical values.

**Table 3.** Shows an example of a resultant output table generated in step 3 above

| Mobile phone trial | | | | |
|---|---|---|---|---|
| EEG Rhythm (Hz) | Rec. Site | % of Subjects Indicating Decrease | 95% CI (μV) | 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 |

*1. Significant p-values indicated at 9 Hz from all 3 recording sites*

*2. Significant p-values indicated at 7 & 9 Hz from both the central and occipital regions*

*3. Significant p-values indicated at consecutive frequencies at 7, 8, & 9 Hz from the occipital region*

*4. Significant p-values indicated at consecutive frequencies at 17 & 19 Hz from the occipital region*

## 4 Discussion

The proposed method of analysis can be useful in determining whether there is an effect in the EEG due to mobile phone exposures for several reasons. In general, the analysis uses an approach by which the raw EEG data is used to identify where probable effects may occur. To do this, firstly the percentage of subjects indicating a decrease or increase in each EEG frequency is identified as described in step 1. It follows in this step that a resultant distribution plot is generated as a function of percentage of subjects indicating a decrease in EEG power versus frequency (Fig. 1(a)). To interpret this figure clearly it is hypothesised that if there is no change in the EEG due to the mobile phone exposure over a given sample size, the distribution at each recording site should tend towards being a uniform 50% over the EEG spectrum. It thus follows the more the percentage of subjects indicating a change in EEG power tends away from 50% the more probable it is that a significant difference occurs in those EEG frequencies demonstrating higher and lower tendencies. Consequently, it is of interest in step 3 to test the statistical significance of difference in these rhythms.
In addition to the generated distributions in step 1, step 2 introduces the use of box diagram plots (Fig. 1(b), Fig. 2). As may be observed, the diagrams represent where the corresponding distributions produced in step 1 lie with respect to each other and their respective recording sites. In particular, this characteristic is very useful in demonstrating how the frequency distributions of recording sites near to the position of a mobile phone RF source may vary with distance.
In the final third step, it is described that a paired t-test analysis is conducted on the median paired data sets in each frequency (Table 2) where 75-100% of subjects indicate an increase or decrease in EEG power. By examining this upper high tendency range (away from 50%) this important stage of analysis significantly reduces analysing large proportions of probable redundant data and concentrates on interpreting more likely affected regions. Statistically significant results determined in this step would therefore be more difficult to disregard as occurring due to statistical chance. Demonstrated in Table 3 is an example of a resultant output table generated from step 3. The table shows four prominent trends which occurred amongst frequencies indicating statistically significant differences in the median control and exposure EEG recorded sets. Results of prominent interest indicated in this example from our previous work [8] were EEG frequencies showing statistically significant changes in EEG power from the occipital region at 7 Hz, 8 Hz, and 9 Hz. It is of particular interest to note for the purpose of this work that this potentially important result indicating significant change in consecutive rhythms extending from within the theta to the alpha EEG range may have otherwise been masked by an analysis in frequency bands due to the two limitations earlier discussed.

## 5 Conclusion

This paper proposes an alternative method to analysing the effects of mobile phone exposures on the EEG in its distinct frequency bands. The main advantage of the proposed analysis is that all frequencies within the EEG spectrum are considered

resulting in a higher resolution analysis to detect potential stimuli from exposure. It is important to point out in such a case where the effects of an external stimulus is of interest that it is not important to conduct analysis of the human EEG in its frequency bands. This is due to the fact that the power in the EEG frequency bands is a physiologically and mentally dependent parameter that presumably does not differ during control and exposure conditions. Thus for linear analysis the EEG may be statistically handled in a manner whereby it is fixed.
Overall, it is thought that the proposed spectral analysis of the EEG is a robust and sensitive method for which to investigate the effects of radiofrequency exposures from mobile phones on the human EEG. We look forward to incorporating and further adapting this method into our current study that is underway to examine the effects of GSM mobile phone exposures on multiple biosignal responses.

## Acknowledgements

We would like to extend our thanks to Dr. Everarda Cunningham for her kind support in reviewing this work.

## References

1. Cook, C.M., Thomas, AW., Keenliside, L., Prato, F.S.: Resting EEG Effects During Exposure to a Pulsed ELF Magnetic Field. Bioelectromagnetics (2005) 26(5):367-76
2. Eulitz, C., Ullsperger, P., Freude, G., Elbert, T.: Mobile phones modulate response patterns of human brain wave activity. Neuroreport (1998) 9: 3229-3232
3. Huber, R., Graf, T., Cote, K., Wittmann, L., Gallmann, E., Mather, D., Schuderer, J., Kuster, N., Borbely, A., Achermann, P.: Exposure to pulsed high-frequency electrogmagnetic field during waking affects human sleep EEG. Neuroreport (2000) 11: 1321-1325
4. Röschke, J., Mann, K.: No short-term effects of digital mobile radio telephone on the awake human electroencephalogram. Bioelectromagnetics (1997) 18: 172-176
5. Hietanen, M., Kovala, T., Hämäläinen, A-M.: Human brain activity during exposure to radiofrequency fieldsemitted by cellular phones. Scandinavian Journal of Work Environment & Health (2000) 26: 87-92
6. Bachmann, M., Kalda, J., Lass, J., Tuulik, V., Säkki, M., Hinrikus, H.: Non-linear analysis of the electroencephalogram for detecting effects of low-level electromagnetic fields. Medical & Biological Engineering & Computing (2005) 43:142-149
7. Lipping, T., Olejarczyk, E., Parts, M.: Analysis of photo-stimulation and microwave stimulation effects on EEG signal using Higuchi's fractal dimension method. Proceedings of SPIE (2004) 5505: 174-178
8. D'Costa, H., Trueman, G., Tang, L., Abdel-rahman, U., Abdel-rahman, W., Ong, K., Cosic, I.: Human brain wave activity during exposure to radiofrequency field emissions from mobile phones. Australasian Physical & Engineering Sciences in Medicine (2003) 26[4]: 162-167
9. Reiser, H.-P., Dimpfel, W. Schober, F.: The influence of electromagnetic fields on human brain activity. European Journal of Medical Research (1995/96) 1: 27-32
10. Sirkin, R. Mark.: Statistics for the Social Sciences. 2nd Edn. Thousand Oaks, Calif.:Sage Publications (1999)
11. Aston R, Principles of Biomedical Instrumentation and measurement, Meril (1990)