

# The effect of high frequency radio waves on human brain activity: an EEG study

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## Abstract

Electromagnetic fields (EMF) produced by electronic devices have long raised public concern. Although no studies have shown brain injury due to the use of these devices, some individuals report developing headaches or localized warming during cell phone use. The aim of this study was to determine the effect of radio frequency EMF on human electroencephalography (EEG) signals. A single blind randomized test procedure was used in this study. Ten healthy subjects were exposed to EMF from a cordless phone and wireless router, which emit at 900 MHz and 2400 MHz, respectively. Three 100 second trials for each condition were conducted on each subject. **The subject's EEG was also measured while wearing a Farabloc® hood which blocks any EMF with frequencies above 1000 Hz.** Neither the cordless phone nor the wireless router produced any significant changes in the EEG of the subjects compared to the control condition. Our results imply that the everyday utilized wireless communication devices, such as wireless phones and routers, have little influence on the electrical activity of the brain in the short term.

## Introduction

Ultra High Radio Electromagnetic Fields (UHR-EMF) are emitted by common electronic communication devices such as cordless phones and wireless routers operating in the 800 MHz to 2400 MHz range. The effects of these waves on the human physiology have raised concerns, particularly their implication on the functioning of the human brain. Several physiological impacts of these EMFs have been reported through human behavioral studies, including decreased reaction time to stimuli and their gender specific effects on human cognitive ability in response to increased exposure to pulse modulated EMF [1, 2]. Another study also found that high frequency radio waves altered the regional cerebral blood flow [3]. As a medical application, EMFs have also been suggested as non-invasive alternatives for controlling brain physiological activities [3, 4]. The EMFs generated by wireless devices are no exception in producing such effects and warrant further understanding of the physiological risks involved with their daily use.

One of the ways to study the function of the brain is by measuring its electrical activity through electroencephalography (EEG). EEG signals are generated by inhibitory and excitatory postsynaptic potentials of cortical nerve cells and recorded by electrodes attached to the subject's scalp [5]. Extensive scientific studies have correlated different EEG signals to different human behavioral activities [6]. The Delta band (< 4 Hz) has been associated with drowsiness, the Theta and Alpha bands (4 – 13 Hz) are predominantly observed in individuals feeling relaxed, and the Beta band (13 – 30 Hz) represents active thinking [7]. Changes in the amplitude or power of these frequency bands represent changes in brain activity that could potentially have important physiological implications.

The principal aim of this study was to investigate the short-term effects of UHR-EMF on the electrical activity of the brain.

Previously, Regel and Huber independently documented an increase in the power of Alpha bands upon exposure to EMFs generated at 900 MHz [3, 8]. Such observations established the precedence for our study. We hypothesized that exposure to high frequency radio waves would transiently alter the resting EEG in one or more of these frequency bands, and that the use of an EMF shield, which blocks out ambient radio waves, would negate this effect of high frequency radio waves on the resting EEG.

## Materials and Method

### Participants

Data from 6 healthy male and 4 healthy female subjects was collected. The subjects were free of any apparent neurological symptoms, and were between the ages of 18 and 25.

### Exposure Equipments

Two sources of UHR-EMF were used in this study: a cordless phone (GM 900) with an emission frequency of 900 MHz and power density of 0.101  $\mu\text{W}/\text{cm}^2$  and a wireless router (Linksys WRT54GL) with an emission frequency 2.4 GHz and power density of 0.0676  $\mu\text{W}/\text{cm}^2$ . **A hood-shaped EMF shield, made of a double layer of Farabloc® material, was also used. This material has been demonstrated experimentally to significantly block EMF above 1000 Hz (1 MHz).**

### Test conditions

Each subject was exposed to a total of 5 different conditions. In one condition the subject was exposed to the EMF emissions from the cordless phone (PhoneON) positioned on the left side of the head in the typical phone orientation. The phone was functioning 'in call' without conversation. An identical condition, which involved the cordless phone switched off (PhoneOFF), served as the sham treatment. In the third test condition, the subject was exposed to emissions from the wireless router placed at

a distance of 2 m in front of the subject's head, equidistant from either side. The fourth test condition involved the hood covering the entire head and neck region of the subject (Hood) making the brain virtually devoid of any exposure to high frequency radio waves. In the fifth condition, which served as the control, all experimental sources of UHR-EMF were turned off and the hood was removed; the subject was only exposed to ambient EMFs.

### Preparation and Data Collection

A 32-electrode cap was used in this study. Each electrode allows for detecting brain activity pertaining to its respective region on the scalp, giving rise a distinct EEG pattern. The reference electrode was positioned on the forehead between the eyebrows where the brain activity variability is minimal. Subjects were seated on a comfortable chair, with the head resting on the chair, in a relaxed position. The impedance of the scalp-electrode interface was adjusted to about 10 k $\Omega$  by the injection of electrolyte paste into the electrodes. During EEG recordings, eyes were closed, visual and auditory distractions were minimized, and no significant movements were made by the subject.

A total of 15 EEG recordings were made: three 100 second recordings associated with each of the five test conditions. A 30 s 'resting' period was allotted after each EEG recording. In order to eliminate the confounding effect of time-dependent tiredness and relaxation on the EEG pattern, the order of the test conditions was completely randomized throughout the 15 recordings, independently for every subject.

The EEG signals from all electrodes were recorded by Grass amplifiers, and digitized by a National Instruments interface which was in turn controlled by data acquisition software written in Labview 8.5. Signals at each electrode were sampled at a rate of 256 s<sup>-1</sup> in a bandwidth of 1-100 Hz. Subsequently, all EEG traces were scanned, and artifacts that are normally a consequence of occasional muscle twitches and mechanical interferences were removed.

### Data analysis

Three physiologically significant frequency bands from the EEG traces were considered in this study: Delta band, Theta/Alpha band, and Beta band. These frequency bands were selected and their powers were calculated for all channels. The spectral power for the left hemisphere (channels 2 – 16) and the right hemisphere (channels 19 – 35) were averaged separately. The spectral power for each channel was normalized with respect to the average power of all the channels in each recording event for each subject. The spectral powers of the subjects were averaged and comparisons were made between different test conditions using paired student t-test with two-tailed significance.

In order to assess the effects of UHR-EMF, the spectral powers associated with PhoneON and Wireless Router were compared with the Control and PhoneON was compared with PhoneOFF, for each side of the brain. Spectral powers associated with Hood were also compared with Control and PhoneON to examine the EMF shielding effects.

## Results

### Direct EMF exposure

The analysis of the average spectral powers in the Delta band ( $P_D$ ), Alpha/Theta bands ( $P_{A+T}$ ), and Beta band ( $P_B$ ) of all subjects as a whole, revealed no significant changes ( $p > 0.05$ ) in the elec-

**Table 1. Spectral powers of all the frequency bands in each test condition.** The average powers and the standard errors (SE) in each frequency band, associated with each test condition for the left hemisphere (LS) and the right hemisphere (RS).

| Test Conditions    | Frequency Bands Power ( $\mu V^2/Hz$ ) |                 |          |                 |          |                 |          |
|--------------------|--|-----------------|----------|-----------------|----------|-----------------|----------|
|                    |  | $P_D$           | SE       | $P_{A+T}$       | SE       | $P_B$           | SE       |
| Control            | LS                                     | <b>0.167028</b> | 0.005228 | <b>0.135772</b> | 0.006558 | <b>0.164575</b> | 0.004295 |
|                    | RS                                     | <b>0.164697</b> | 0.005401 | <b>0.147623</b> | 0.004469 | <b>0.156625</b> | 0.004481 |
| Farabloc® Hood     | LS                                     | <b>0.11641</b>  | 0.018582 | <b>0.12096</b>  | 0.013167 | <b>0.133706</b> | 0.017238 |
|                    | RS                                     | <b>0.110364</b> | 0.016402 | <b>0.126106</b> | 0.009333 | <b>0.122895</b> | 0.012707 |
| Cordless Phone ON  | LS                                     | <b>0.160463</b> | 0.005944 | <b>0.134906</b> | 0.007099 | <b>0.158559</b> | 0.004816 |
|                    | RS                                     | <b>0.157475</b> | 0.008161 | <b>0.143247</b> | 0.00495  | <b>0.158135</b> | 0.006484 |
| Cordless Phone OFF | LS                                     | <b>0.161059</b> | 0.006663 | <b>0.143157</b> | 0.00626  | <b>0.164535</b> | 0.004287 |
|                    | RS                                     | <b>0.145556</b> | 0.010221 | <b>0.142157</b> | 0.005872 | <b>0.1565</b>   | 0.005914 |
| Wireless Router    | LS                                     | <b>0.159341</b> | 0.008822 | <b>0.138736</b> | 0.005088 | <b>0.161574</b> | 0.003434 |
|                    | RS                                     | <b>0.156937</b> | 0.012124 | <b>0.147573</b> | 0.004823 | <b>0.157458</b> | 0.006199 |

trical activity of the brain upon exposure to UHR-EMFs emitted from the phone. However, the EEG patterns of two subjects were significantly increased, suggesting an individual variation in the sensitivity to these EMFs. No significant disparity in response to UHR-EMF was observed between the left hemisphere (LH) and the right hemisphere (RH) of the brain. (Table 1, Figure 1a) In order to eliminate any confounding effects of subject's awareness of the phone, a comparison between the PhoneON and the sham treatment – PhoneOFF, was made. No statistically significant changes were observed, confirming that the EMF emissions from the phone were not imposing any changes to the EEG. Similar results were obtained when comparing the wireless router treatment with the control (data not shown).

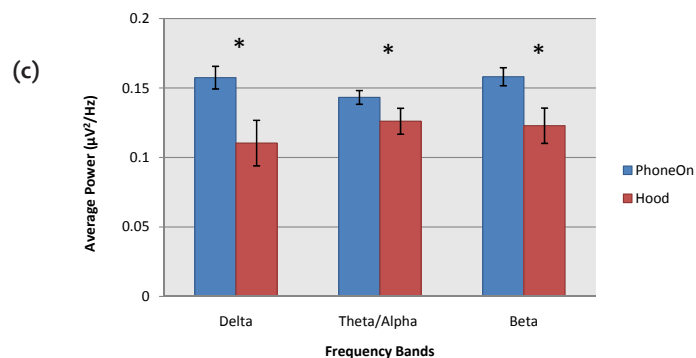
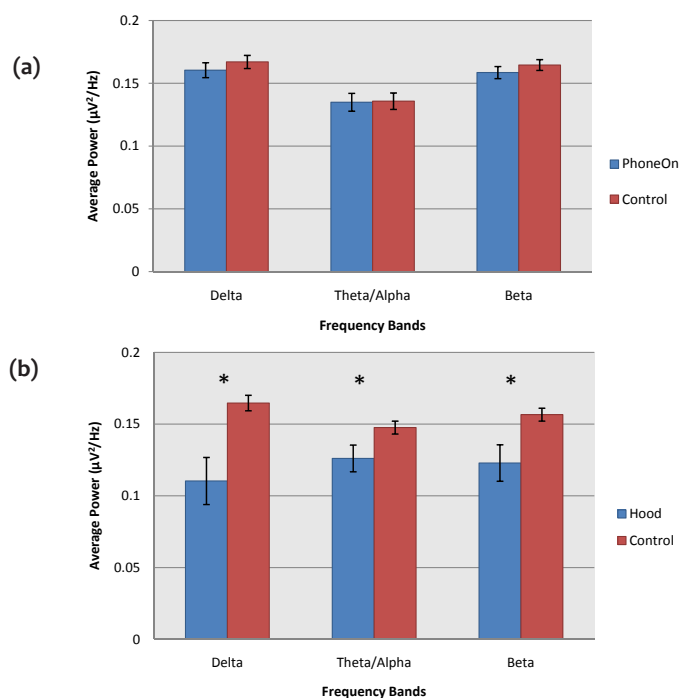
### EMF shield

In order to determine whether or not EMF shielding influences the EEG pattern in an opposite manner compared to that of EMF exposure, spectral powers associated with Hood treatment were analyzed.

Comparison between average spectral powers revealed that EMF shielding – Hood treatment – significantly ( $p < 0.05$ ) reduced power of all frequency bands compared to the control (Figure 1b);  $P_D$ ,  $P_{A+T}$ , and  $P_B$  were reduced by 10% - 30% on either side of the brain (Table 1). In order to further investigate the effectiveness of the hood, average spectral powers of PhoneON and Hood treatments were also compared. A similar trend of decrease in spectral powers of all three frequency bands was noted (Figure 1c).

## Discussion

The purpose of this study was to investigate the short term effects of UHR-EMF exposure on the electrical activity of the brain using EEG power analysis of three physiologically relevant frequency bands - Delta, Alpha/Theta, and Beta. We have demonstrated that the exposure to high frequency radio waves does not impose significant changes on any of these frequency bands in short term EEG patterns, rejecting our hypothesis that UHR-EMFs transiently alter the electrical activity of the brain. This finding is in agreement with the results reported by some previous studies. Rochske and Mann found no significant changes in the spectral power of healthy male volunteers that were exposed to EMF emitted at 900 MHz [9]. Hietanen and colleagues also found no effects on the EEG by several different cell phones emitting at different frequencies [10].



**Figure 1. Comparison between average powers of different test conditions in the right hemisphere of the brain.** The comparisons of powers associated with delta, theta/alpha, and beta bands between different test conditions are depicted; PhoneON vs. control (a), Hood vs. control (b), and PhoneON vs. Hood (c). Similar patterns were observed on the other side of the brain. The Y-axis in these graphs represents the average power in units of  $\mu\text{V}^2/\text{Hz}$ . Statistical significance ( $P < 0.05$ ) is denoted by (\*). Error bars represent  $\pm$  standard error. **The power of all frequency bands were significantly increased in the PhoneON compared to Hood, and Control compared to Hood, whereas there were no statistically significant results for the PhoneON vs. Control testing condition.**

Nevertheless, there are a few studies that have reported an increase in the alpha waves in response to cell phone EMF exposure [3, 8, 11, 12]. For instance, Huber et al reported an increase in the power of alpha activity; however it was observed in simulated conditions using pulse modulated waves [3]. The difference between the reported results can be attributed to several factors. First, given the considerable difference in the protocols and the settings of these studies, it is reasonable to expect different results being produced. Second, these studies have considered different periods of exposure to EMF and studied the changes in the EEG on different time scales. We considered the immediate changes in the EEG signals during 100 seconds EMF exposures, whereas some studies examined EEG signals up to 30 minute after exposure [8].

This is the first study to explore the effects of EMF shields on human brain activities using EEG. Based on the current literature, which suggests that EMFs may cause an increase in EEG spectral power [8, 11, 12], it is reasonable to expect the Farabloc<sup>®</sup> hood, acting as an EMF shield, to cause a decrease in EEG spectral power. Given that the Farabloc<sup>®</sup> hood treatment did result in a significantly lowered spectral power compared to both the cordless phone and the control (Figure 1b, c), we cannot rule out the possibility that ambient radio waves are chronically affecting human resting EEG. Some may argue that the decrease in the spectral power may be, at least partly, attributed to a reduction in perceived light intensity caused by the hood; however, it is generally accepted that a reduction in light intensity—as the case when closing the eyes—increases the power of alpha waves [5]. Similarly, any drowsiness elicited by darker conditions would increase EEG power in the Delta band, the opposite of what was observed [5].

Since the Farabloc<sup>®</sup> hood tests indicated that ambient radiation has a significant effect on the resting EEG, an alternative explanation for our results is feasible. The ambient radiation may have a tonic ‘saturating’ effect on EEG such that an extra influence from phasic EMFs produced by the cordless phone and router is occluded. Moreover, all of the subjects were regular cellphone users; their brains may have adapted to the EMFs used in this study. For future studies, it would be perhaps insightful to extend the investigation to incorporate subpopulations that are more sensitive to EMFs emitted

by wireless devices. Also, given the difficulty faced in comparing our results with previous similar studies, we propose the incorporation of a standardized set of protocols and test conditions that would allow for more meaningful interpretations of the results.

## Conclusion

The present data provides no evidence for an immediate effect of acute UHR-EMF exposure on human EEG. Our results imply that the everyday utilized wireless communication devices, such as wireless phones and routers, have little (if any) influence on the electrical activity of the brain in the short term. However, exposure to ambient EMFs may be chronically influencing brain activity as demonstrated by the hood treatment.

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