Mobile Telecommunications and Health Research Programme

# Detection of Effects of Microwave Radiation on the Electrical Activity of the Brain

S Butler

RUM 21

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# Detection of Effects of Microwave Radiation on the Electrical Activity of the Brain

RUM 21

**Dr S Butler***

## 1. Executive Summary

A number of behavioural studies published between 1999 and 2003 reported that cognitive function was facilitated when people were exposed to the microwave radiation from mobile telephone handsets. In particular it was found that reaction times were shortened. The objective of the present study was to determine how the radiation affected the activity of the brain to bring about the shortened reaction times. To address the issue, four experiments were carried out in which the electrophysiological activity of the brain was measured under different conditions of exposure to microwave radiation.

In Experiment 1, the electrical activity of the brain was recorded from electrodes on the scalp during exposure to (a) 400 MHz Carrier Wave radiation, (b) TETRA (Terrestrial Trunked Radio) modulated 400 MHz radiation and (c) in a Sham condition. The brain's responses to stimulation in different sensory modalities (known as visual, auditory and somaesthetic 'evoked potentials') were recorded as well as its electrical activity during cognitive processing (visual and auditory 'event related potentials'). The timing and amplitude of these electrical signals were measured to determine whether they were affected by the microwave radiation. Of particular interest was the possibility that the latency of the responses would be shortened, thereby providing an explanation for the shortening of reaction times. Where the procedures allowed, reaction times were measured during the recordings of the electrophysiological signals.

In Experiment 2 similar recordings were made of evoked potentials and reaction times while subjects performed two of the tasks used in a previous study in which shortening of reaction time during exposure to modulated microwave radiation had been observed.

In Experiment 3 the electroencephalogram (EEG) was recorded under the three exposure conditions to determine whether its frequency spectrum (and therefore the activity of the brain) was altered in the presence of microwave radiation.

In Experiment 4 the hypothesis was tested that the pulses of radiation from a mobile phone handset reduced reaction time by bringing forward and synchronising the moment of discharge of nerve cells in the brain. It was predicted that if this process was occurring, pulses of 400 MHz radiation would evoke electrical activity in the brain which could be detected in recordings from electrodes on the scalp.

No statistically significant effects of either TETRA modulated or Carrier Wave radiation were found in the electrical activity of the brain in Experiments 1, 2 or 3. Pulses of microwave radiation failed to evoke detectable responses in the brain in Experiment 4. In accord with the most recent behavioural studies, this investigation failed to replicate the earlier findings that exposure to microwave radiation shortened reaction times.

This study has found no evidence that microwave radiation at the levels radiated by the supplied TETRA handsets has any detectable effect on the electrical activity of the brain or on cognitive function. Findings to the contrary in earlier studies may be due to flaws

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in their design or to the use of more powerful, analogue handsets.

## 2. Aims and Objectives

The microwave radiation emitted by mobile telecommunication devices is thought to interact with biological tissue only by raising its temperature (NIEHS, 1998). The power radiated by mobile phones is therefore limited by legislation to ensure that any thermal effects on phone users are well within the range of normal variation in body temperature.

However reports began to appear in 1999 which described changes in cognitive function associated with exposure to radiation from mobile phones (Preece *et al*, 1999; Koivisto *et al*, 2000a,b; Lass *et al*, 2001; Lee *et al* 2001, 2003; Edelstyn and Oldershaw, 2002; Smythe and Costall, 2003).

These investigators reported enhancements in cognitive function measured in terms of reaction time, selective attention and memory. In addition, there has been one report of an impairment in auditory discrimination performance after protracted exposure to radiation from a mobile phone (Maier *et al*, 2004). Although behavioural changes have not been found in every study, particularly the more recent ones (Hladky *et al*, 1999; Haarala *et al*, 2003; Haarala *et al*, submitted; Preece *et al*, 2005), the early publications describing unexpected effects on cerebral function were sufficient to raise concern about longer-term risks to human health (Stewart, 2000).

The possibility that microwave radiation at the intensity emitted by mobile communication systems has a direct effect on cerebral function would be supported if it were found to alter the electrical activity of the brain. Such evidence would not only support the behavioural evidence for a hitherto unknown interaction between microwave radiation and the brain; it might also provide some insight into the mechanisms involved.

The literature on the effects of non-thermal levels of microwave radiation on the electrical activity of the brain is limited. In studies of the EEG under various conditions of arousal and mental activity some authors have found changes in the power or prevalence of activity in certain frequency bands (Shandala *et al*,1979; Kramerenk and Tan, 2003; Roschke and Mann, 1997; Borbely *et al*, 1999; Lebedva *et al*., 2001, Huber *et a*l, 2000, 2002; Krause *et al*, 2000a,b; Lebedva *et al*, 2000; Croft *et al*, 2002; Marino *et al*, 2003) while others have not (Eulitz *et al*, 1998; Wagner *et al*, 1998; Hietanen *et al*, 2000; Jech *et al*, 2001; Krause *et al*., 2004). None of the reported effects has been independently replicated and where replications have been attempted they have failed (Mitchell *et al*, 1989, Krause *et al*, 2004). Studies of evoked potentials are similarly divided. Some have reported effects on amplitude or latency (Freude *et al*, 1998; Maby *et al*, 2004; Hamblin *et al*, 2004; Jech *et al*, 2001) while others did not (Eulitz *et al*, 1998; Arai *et al*, 2003; Urban *et al*, 1998; Hladky *et al*, 1999). Again, none of the reported effects has been independently replicated. The failure of the existing literature to provide a clear picture of whether non-thermal levels of radiation affect the brain is due at least in part to deficiencies in the design and execution many of the published studies (Hamblin and Wood, 2002).

The present study employed a number of different electrophysiological approaches to the problem. Two experiments were designed to measure the effects of microwave radiation on sensory and cognitive processing by recording sensory and event related potentials during exposure to modulated and to carrier wave microwave radiation and also during sham exposure.

A third experiment examined the effects of microwave radiation on the spectral composition of the electroencephalogram because this provides a global measure of the brain's electrical activity.

Finally, a fourth experiment looked for evidence that pulses of microwave radiation evoke electrical responses in the brain. Mobile telecommunication devices emit a stream of pulses of electromagnetic radiation. If these pulses forced neurons which were close to initiating action potentials over their discharge thresholds (by some as yet unknown mechanism), then the overall effect would be to increase the speed of cerebral processing, thus shortening reaction time. This process, if it occurred, would also have the effect of synchronising the discharge of many neurons to the microwave pulses. The synchronisation of large numbers of neurons generates extraneuronal currents whose density may be sufficient to induce voltages which are detectable at the scalp. If pulses of microwave radiation were found to evoke such electrical activity, this would not only provide direct evidence that exposure affected brain activity, it would also provide an explanation for why the effect was to reduce reaction time.

## 3. Participants

Dr Stuart Butler, MA, PhD, Scientific Director, The Burden Neurological Institute, Bristol

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## 4. Achievements

### 4.1 Methods

#### 4.1.1 The microwave source

Standard TETRA (Terrestrial Trunked Radio) handsets were provided by MTHR for this study. They were equipped with coded switches to enable them to transmit a TETRA modulated 400 MHz signal of 0.75 W mean power (3 W peak), or 400 MHz carrier wave (0.75 W mean power) or to dissipate their output into an internal load as a sham exposure condition.

#### 4.1.2 Recording behaviour and electrophysiological signals in the presence of microwave fields

It was anticipated that a number of problems might be encountered in making electrophysiological recordings in the presence of radiation from these handsets. First, the presence of electrodes and the wires from them might be expected to distort the radiofrequency field and alter the Specific Absorption Ratios (SARs) during radiation. A phantom head was constructed and SARs were measured with and without the electrodes and cables in place. SARs were found to be perturbed by no more that 6% by the presence of cables and electrodes.

Secondly it was expected that the radiofrequency field might induce noise in the physiological amplifiers which might obscure the signals from the brain. A number of different amplifiers were tested and a system was identified that picked up less than 4 μV of interference at 17.6 Hz (the TETRA modulation frequency). This was small enough to disappear during the averaging of evoked potentials and could be digitally filtered out of the electroencephalogram in Experiment 3.

Modulated radio frequency signals can interfere with the images on visual display units and induce noises in headphones. The study was designed as a double-blind investigation and would be unblinded to the subjects and experimenters by such phenomena. After careful screening, no effects on either the visual or auditory stimulators were detectable.

Finally, there was a possibility that the study might be unblinded by noise from the handset batteries during the17.6 Hz modulation of the TETRA signal. In a forced choice discrimination test on 18 children with normal hearing, this was found to be undetectable. The adults who took part in the physiological studies were also asked to guess when the handset was transmitting. Their accuracy did not differ from chance.

### 4.1.3 Subjects

Groups of 18 subjects aged between 18 and 39 participated in these experiments. Inclusion criteria were normal or corrected-to-normal vision and hearing thresholds and threshold +60 dB within the range of the auditory stimulator. Subjects with a history of head injury or neurological disorder were excluded.

### 4.1.4 Randomisation

The handsets were supplied with coded selector switches so that both the experimenter and the subjects would be blind to the exposure condition. Each condition could be selected by many different code numbers so that no code number was used repeatedly across subjects during the experiments. In Experiments 1, 2 and 3 recordings were made under all three conditions (TETRA, Carrier Wave and Sham) from all subjects. All six possible orders of exposure to the three conditions were repeated three times across the 18 subjects in each set of recordings. A statistician who took no part in the experiments compiled a list of codes for use in each recording session to achieve the fully balanced randomisation of exposure conditions across subjects. The data were unblinded for statistical evaluation only after they had been measured.

### 4.1.5 Experiments 1 and 2

To investigate the mechanism by which reaction times appeared to be reduced in the presence of microwave radiation, evoked potentials were recorded in order to measure the effects of the radiation on the timing of sensory and cognitive processing. Evoked potentials are electrical signals from the brain that can be detected in recordings from electrodes on the scalp. By averaging the responses to many stimuli, the background electrical activity of the brain (the electroencephalogram, or EEG) cancels out and responses time locked to the stimuli reinforce one another. The resulting electrical signals reveal something of the sequence of events in areas of the cerebral cortex involved in sensory and cognitive processing.

In Experiment 1, evoked potentials were recorded to visual, auditory and somaesthetic stimuli and also during the performance of auditory and visual tasks which involved cognitive activity. The signals recorded in this part of the investigation are standard tools in the fields of clinical neurophysiology and psychophysiology where they are used routinely for diagnostic purposes or to investigate normal cerebral function:

a) Visual evoked potentials were recorded to a reversing black and white chequerboard, the checks subtending 1 degree and reversing every 500 ms. Responses were averaged to 200 stimulus reversals. The latency and amplitude of the P100 component of the evoked potential were measured.

b) Auditory evoked potentials were recorded to 1000 Hz tone bursts 60 dB above threshold Responses were averaged to 200 stimuli. The latency and amplitude of the N100 component were measured.

c) Somaesthetic evoked potentials were recorded to electrical stimulation of the right median nerve at the wrist. Stimuli were supramaximal and 200 µs in duration. Responses were recorded to 512 stimuli. The latency and amplitude of the N19 component were measured.

d) Visual event related potentials (ERPs, also known as cognitive evoked potentials) were recorded using a checkerboard stimulator to provide the common, ‘standard’ stimuli. Subjects had to detect ‘target’ stimuli which comprised an incomplete reversal of a central square in the checkerboard. This was used to evoke the ERP known as P3b, a component generated by several different areas of the brain concerned with both attention and perceptual discrimination. The subjects signalled that they had detected a target by pressing a button and this enabled reaction times to targets to be measured. Subjects were instructed to ignore 'novel' stimuli - coloured photographic images presented randomly in place of a checker board reversal. These were included to evoke the ERP known as P3a, a component associated with involuntary attention switching. Target and novel stimuli each comprised 10% of all stimuli and the signals were averaged until responses had been collected to at least 64 targets and 64 novel stimuli.

e) Auditory ERPs were collected using 1500 Hz tone bursts as the common stimuli. Subjects were asked to detect 1000 Hz target stimuli to evoke an auditory P3b and reaction times to the targets were measured. They were asked to ignore environmental sounds used to evoke P3a. Targets and novel stimuli each comprised 10% of all stimuli and the signals were averaged until responses were collected to at least 64 targets and 64 novel stimuli.

In Experiment 2 we recorded evoked potentials elicited during the performance of tasks which were used in our initial study of the effects of microwave radiation on reaction time (Preece *et al*, 1999):

a) Verbal choice reaction time. Subjects watched a visual display unit and had to press a button labelled 'Yes' or 'No' when the corresponding word appeared on the screen. In our 1999 study, reaction time on this task was reduced during exposure to radiation from an analogue mobile phone handset. The task was found to evoke a P3b ERP and its amplitude and latency were measured. Reaction times to the verbal stimuli were also measured.

b) Visual working memory task. Subjects studied a picture of a house with nine windows, five of which were illuminated. They were then shown repeated images of the house in which only one window was illuminated and they had to press buttons labelled 'Yes' or 'No' if the single window had been illuminated in the original image. This task had been unaffected by exposure to microwave radiation in our 1999 study and was included here as a control. It was found to evoke two well studied ERP components, namely N2b and P3b. Reaction times to the test stimuli were measured.

To record the evoked potentials signals were averaged from 16 scalp electrodes distributed widely over the scalp from frontal to occipital regions and over both hemispheres. The signals were recorded with respect to a frontal reference electrode (Fz) but subsequently re-referenced to the right mastoid (A2) where signals of interest occurred at Fz. Sensory evoked potentials were digitised at 2000 Hz while those involving ERGs were digitised at 1000 Hz. The band pass of the amplifiers differed according to expected frequency content of each type of evoked potential. Epoch lengths varied from 64 ms for the somatosensory evoked potentials up to 2048 ms for the visual working memory task.

### 4.1.6 Experiment 3

In this part of the study the effects of radiation on the spontaneous EEG were examined. The EEG is a signal whose energy is almost entirely contained in the bandwidth 1 Hz to 70 Hz and this can be quantified for different frequency bands using the fast Fourier transform to compute the amplitude spectrum.

Forty seconds of EEG were recorded with the subjects' eyes closed and 40s with eyes open under each of the three exposure conditions in balanced randomised order over 18 subjects. The EEG was recorded over the bandwidth 0.1 Hz to 70 Hz and its spectral power was computed in each of the standard frequency bands (delta, theta, alpha, beta 1, beta 2 and gamma).

### 4.1.7 Experiment 4

Whereas Experiments 1, 2 and 3 looked for evidence of an effect of microwave radiation on the normal activity of the brain, Experiment 4 looked for an entirely novel phenomenon: electrical responses in the brain to pulses of microwave radiation. The existence of such responses would provide evidence that pulses of microwave radiation bring forward the moment of discharge of nerve cells which are already close to their discharge thresholds and so shorten reaction time.

For this part of the study a modified TETRA handset was employed which could be made to emit short pulses of 400 MHz radiation under the control of the experimenter. The search for responses to pulses of radiation was made in 12 subjects. Pulse lengths of 1 ms and 14 ms were used, the former to ensure that very short latency responses could be detected and the latter because it corresponds to the burst length of TETRA modulated signals.

The EEG was recorded from the same electrodes as in the earlier experiments, digitised at 8 kHz, and responses were recorded to 500 pulses or sham pulses.

### 4.1.8 Statistical analysis

Both the physiological data and the reaction times were subjected to Analysis of Variance (ANOVA) using SPSS Version 11 software. Reaction time data was analysed with a One Way ANOVA with the single factor EXPOSURE with repeated measures on subjects. The electrophysiological data of Experiments 1, 2 and 3 were analysed with a Two Way ANOVA with the factors EXPOSURE and ELECTRODES with repeated measures on subjects. Significance levels were corrected for sphericity using the Huynh-Feldt method and, because the analyses involved a large number of contrasts, significance levels were corrected for multiple comparisons with the Bonferroni correction.

The possibility that the study was unblinded by an ability of the subjects to detect the radiation condition was tested by asking subjects to guess when the handsets were transmitting. The frequencies of judgements in the different conditions were compared with $x^2$ tests.

In Experiment 4, the amplitude of the recorded signals in the period following the microwave pulses was assessed with One Sample Student-t tests and the difference between the trace amplitudes after real and sham pulses was tested using a Two Way ANOVA (EXPOSURE x ELECTRODE) with repeated measures on subjects.

## 4.2 Results

There were no significant effects of either TETRA modulated or carrier wave radiation on the reaction times measured in Experiments 1 and 2. The direction of differences between the reaction times under the three exposure conditions varied among the four tasks in which this variable was measured.

After correction for multiple comparisons, there were no significant effects of radiation condition on the amplitudes and latencies of any of the evoked potentials (P100, N100 and N19) or ERPs (P3a, P3b and N2b) measured in Experiments 1 and 2.

Visual and auditory evoked potentials were recorded not only during passive stimulation but also in the course of evoking the ERPs. There was therefore more than one opportunity to measure P100 and N100 during the study. Similarly P3b was measured not only during the auditory and visual ERPs in Experiment 1 but again during both the tasks employed Experiment 2. The direction of differences between the amplitudes and latencies of these components varied between the repeated measurements of the same potential.

The ANOVAs tested the interaction ELECTRODES x EXPOSURE to determine whether the radiation had effects only at particular electrodes sites – for example those nearest the handset. This effect did not reach statistical significance at any electrode site in any of the components measures in Experiments 1 and 2.

In Experiment 3, the power in the six EEG frequency bands was measured while subjects relaxed with eyes open and with eyes closed. Exposure to TETRA or carrier wave radiation had no significant effect on the power in any band, nor selectively at particular electrodes. The direction of differences between the radiation conditions was not consistent across frequency bands or between corresponding frequency bands with eyes open and closed.

In Experiment 4, grand averages of signals following 1 ms and 14 ms radiation pulses were computed from 500 responses in each of 12 subjects (6000 sweeps in total). These recordings were repeated with different epoch lengths and with different amplifier bandwidths. No deflections that might have been evoked potentials were evident in the traces, possible candidates were not replicated in recordings across subjects or under the different recording conditions, and no effects reached statistical significance.

Exposure to TETRA modulated and Carrier Wave radiation was not found to have any effects on either the electrophysiological signals or behavioural measures in this series of experiments

## 4. Analysis of Objectives Met

From a purely technical point of view, this study met all of its objectives. It recorded all the electrophysiological signals it set out to measure without the problems of radiofrequency interference with the electronics of the amplifiers and data acquisition system which have plagued the efforts of some investigators in this field. We were also able to show that its status as a double-blind experiment was not compromised by either the noise said to be emitted by the handsets during TETRA transmissions or by the effects of that radiation on the recording or stimulating apparatus.

The study reached a conclusion on each of the questions it set out to address. It did not replicate the effects of radiation on reaction time found in early studies in this field. If reaction time had been reduced in the presence of modulated or carrier wave radiation then we would have expected to find out whether brain activity was facilitated at the sensory, cognitive or motor stages of cerebral processing and also whether any effects were modality specific. However, consistent with the reaction time data, the electrophysiological recordings revealed no effects of radiation exposure on the timing of cerebral processing or measures of spontaneous brain activity. Also consistent with these findings was the absence of any evidence that pulses of microwave radiation directly evoke detectable activity in the brain.

## 5. Interpretation

In our original report that reaction time was reduced during exposure to microwave radiation (Preece *et al*, 1999), the effect was obtained with an analogue mobile phone handset but not during exposure to radiation from a GSM handset which operated at a lower mean power. Some other laboratories did obtain evidence for the facilitation of cognitive activity using GSM handsets but more recent studies using double-blind procedures have failed to replicate these findings (Haarala *et al*, 2003; Preece *et al*, 2005).

Consistent with this, the current double-blind study found no detectable effect on reaction time of radiation from the relatively low powered, digitally modulated signal from a TETRA handset. This is supported by the absence of significant effects of radiation on the timing of cognitive processing as measured by sensory and cognitive event related potentials, by the absence of any detectable effect on the power spectrum of the EEG and by the absence of detectable neuronal responses to pulses of 400 MHz radiation at the non-thermal levels used in these experiments.

How do these findings accord with the existing literature in this field? In fact studies of the effects of non-thermal levels of microwave radiation on the brain are few in number. They have looked at a variety of psychophysiological and electrophysiological phenomena but no reliably reproducible effect has emerged from the published studies. On the other hand there are a number of failures to replicate. The absence of significant effects in the present study does not run counter to any reliable, repeatable effect reported elsewhere.

## 6. Future Priorities

When these experiments were first conceived the research literature seemed to indicate that radiation from mobile telecommunication devices had unexpected effects on behaviour. The experiments were designed to provide confirmation of these effects and to provide some understanding of the underlying mechanism of action. With improvements in experimental design implemented in the MTHR programme and possibly with the change from analogue to digital technology, there is no longer convincing behavioural or physiological evidence that current communication devices have detectable effects on the brain or behaviour. At least, not from the type of evidence considered above. Though the situation might change, the evidence base does not at present point to further work along the present lines except perhaps for independent replication of what we have found.

## 7. Publications

None yet.

## 8. Financial Summary

| | Financial year | | Total |
|---|---|---|---|
| | *1.7.2003—31.3.2004* | *1.4.2004—31.12.2004* | |
| | **£** | **£** | **£** |
| Salary | 33,864 | 27,038 | 60,902 |
| NI | 2,911 | 2,859 | 5,770 |
| Superannuation | 4,228 | 3,205 | 7,433 |
| Total | 41,003 | 33,102 | 74,105 |
| Travel expenses | 96 | 2,904 | 3,000 |
| Other expenses | 3,848 | 1,056 | 4,904 |
| Overheads (40% Salary costs) | 16,401 | 13,241 | 29,642 |
| TOTAL | 61,348 | 50,303 | 111,651 |

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