

## Performance measures and cognitive processing in response to acute exposure to RF EMF emitted by mobile phones

Riccardo Russo<sup>1</sup>, Elaine Fox<sup>1</sup>, Angela Boldini<sup>1</sup>,  
Caterina Cinel<sup>1</sup>, Margaret Defeyter<sup>2</sup>

<sup>1</sup>Department of Psychology – University of Essex – Colchester – UK

<sup>2</sup>Northumbria University – Newcastle – UK

- Recent studies (e.g. Preece et al., 1999; Koivisto et al, 2000; Edelstyn et al. 2002; Curcio et al. 2004; Keetley et al. 2006) have suggested that the use of mobile phones may affect cognitive functioning. However, a closer scrutiny of these studies suggests that, since the probability of wrongly rejecting a true null hypothesis was quite high (i.e. > 5%), these findings could simply reflect a statistical artefact.
- The main aim of the present research intends to overcome the limitations of previous studies providing a thorough evaluation of the impact of the use of GSM and analogue phones on attention and memory in adults. Different groups will be exposed to REF emitted by GSM and by analogue phones, respectively.
- A series of laboratory controlled experiments had been conducted where different samples of about 160 volunteers per experiment (thus highly powered studies) performed a series of attention and memory tasks both while exposed and while not exposed to radiofrequency electromagnetic fields (REF) emitted by the antenna of mobile phones.

## Performance measures and cognitive processing in response to acute exposure to RF EMF emitted by mobile phones

- REF will be generated in the laboratory using a signal source device covering 888 MHz GSM and analogue frequencies.
- The level of specific energy absorption rate (SAR) is the same for both unmodulated and GSM signals (with SAR always within the ICNIRP guidelines. The average SAR in both modes was 1.4 W/Kg (+/- 30%). For the GSM mode the peak SAR was 11.2 W/Kg (CW does not have a peak). The SAR in the no exposure condition was less than 0.002 W/Kg. These features correspond to the approved exposure system made for the Mobile Telecommunication and Health Research Programme ([http://www.mthr.org.uk/meetings/nov\\_2002/summaries/human\\_exposure.htm](http://www.mthr.org.uk/meetings/nov_2002/summaries/human_exposure.htm)) in the UK.

## Example of some results and limitations of early studies

### E.g. Koivisto et al. 2000

Effects of 902 MHz electromagnetic field emitted by cellular telephones on response times in humans

- 48 subjects tested in two sessions. The subjects completed the experimental tasks twice: once with and once without the RF exposure (single blind). Half of the subjects received the RF exposure in the first session and half in the second one.

	Mobile OFF Mobile ON		P value
	Mean RT	Mean RT	
<b>Simple Reaction Time Task</b>			<b>0.026</b>
2-Choice RT	282	273	
10-Choice RT	418	416	> .50
Subtraction	683	696	0.072
(Subtraction - 10CRT)	927	912	0.492
Sentence Verification	245	216	<b>0.044</b>
<b>Vigilance</b>	703	681	0.412
Shape detection	517	492	<b>0.001</b>
Object detection	521	521	> .50
Object familiarity detection	527	531	> .50
Semantic picture categorization	641	635	> .50
Semantic word categorization	552	546	> .50
Object name retrieval	600	592	> .50
	833	822	> .50

## Example of some results and limitations of early studies

Three significant differences between the two exposure conditions were detected. However, the significant p-values were .026 (simple reaction time task), .044 (reaction time in an arithmetic task) and <.001 (reaction time in a sustained attention task), applying the Bonferroni procedure to keep the overall probability of committing a Type I error in the set of statistical tests performed at .05, only in the sustained attention task it could be concluded that exposure to REF emitted by GSM phones affected cognitive functions.

Tasks used in Koivisto et al 2000 associated to significant results

- Simple reaction time (SRT) task a '0' stimulus was presented (40 trials) until the subject pressed the '0' button. After the response, the next stimulus appeared with a random delay ranging from 1000 to 4000 ms.
- Ten-choice reaction time (10-CRT) task numbers ranging from 0 to 9 appeared in random order (40 trials). The task was to press the button with a corresponding number on it (on the standard number keys).
- The subtraction task was identical to the 10-CRT task with the exception that the subjects were asked to subtract the number appearing on the screen from nine and press the button for the remainder.
- The vigilance task took 15 min to accomplish. Different letters were presented for 200 ms with a random 500±3000 ms interval between them. The subjects were asked to press the space bar as soon they saw the letter L, M, or Y. Fifteen percent of the letters were targets.

## Key research questions

- Given the restricted number of studies on the effects of low-level REF emitted by analogue and GSM mobile telephones on cognitive functioning and given their limitations, the present research intended to provide a thorough evaluation of the impact of the use of mobile communication devices on attention and memory.
- **Key research questions addressed by this research:**
- Does exposure to low-level radiofrequency electromagnetic fields (900 MHz) generated by the antenna of standard mobile phones (GSM and analogue) affect adults' performance in attention and memory tasks?
- Is there a lateralised effect (i.e. left vs. right) of low-level radiofrequency electromagnetic fields exposure?
- To this aim, a series of laboratory controlled experiments were conducted. Adult participants were given a series of tasks to assess their attention and memory both when exposed and when not exposed to low-level REF emitted by the antenna of a standard mobile telephone handset.
- Double blind testing conditions.
- To evaluate lateralised effects of exposure to REF, subjects were assessed with the mobile phone positioned either on the right ear or on the left ear. As in the previously described studies, subjects were tested while exposure was occurring/not-occurring.

## Outline of the procedure used

- In the experiments, exposure occurred while subjects were given a series of cognitive tasks to perform.
- Each subject was tested on two different days (a week apart) in order to obtain a measure of performance when the telephone was inactive, and when the telephone was emitting REF directly either from the left side (group A) or from the right side (group B).
- Half of the subjects in each group were exposed to GSM phones operating at 888 MHz with a peak power of transmission of 2 W (about 0.25 W, average); the second half of the subjects were exposed to a continuous signal at 888 MHz of frequency having the same SAR as the digital GSM exposure condition. The order of exposure in the two experimental sessions (i.e. on/off) was counterbalanced across subjects. Subjects and experimenters were blind to the on/off REF exposure condition administered.
- To avoid any spurious effect due to added use of mobile phones, subjects were also asked not to use any mobile phone device at least for 1 hour before the beginning of the test session.
- In order to evaluate attention and memory the following tasks were used. In particular, in order to see if previous findings could be replicated, the same tasks that showed a significant effect of low-level REF exposure in Koivisto et al. (2000 a, 2000 b; see also Preece et al., 1999) were also used.

## Outline of the procedure used

- In Experiment 1 168 adults subjects were tested in two different sessions using the following tasks administered in a Latin square counterbalanced order: Simple reaction time task (about 5'); b) 10-choice and Subtraction tasks (about 15'); c) Vigilance task (about 15').
- In Experiments 2 and 3 we manipulated cognitive load, since previous studies have claimed that any improvement in cognitive function due to REF exposure might only occur under conditions that impose a relatively high cognitive load (Koivisto et al, 2000a).
- In Experiment 2 a new independent sample of 160 adults subjects were tested in two different sessions using the following tasks administered in a Latin square counterbalanced order:
  - Vigilance task (easy and difficult versions - about 15')
  - N-back task (about 30' - with unfamiliar faces and letters).
- In Experiment 3 a new independent sample of 168 adults subjects were tested in two different sessions using the following tasks administered in a Latin square counterbalanced order:
  - Sternberg task (pictorial stimuli); Visual search task (letters); Stroop task (digits).

## Experiment 1 Tasks

- Simple reaction time (SRT) task a '0' stimulus was presented (40 trials) until the subject pressed the '0' button. After the response, the next stimulus appeared with a random delay ranging from 1000 to 4000 ms.
- Ten-choice reaction time (10-CRT) task numbers ranging from 0 to 9 appeared in random order (40 trials). The task was to press the button with a corresponding number on it (on the standard number keys).
- The subtraction task was identical to the 10-CRT task with the exception that the subjects were asked to subtract the number appearing on the screen from nine and press the button for the remainder.
- The vigilance task took 15 min to accomplish. Different letters were presented for 200 ms with a random 500±3000 ms interval between them. The subjects were asked to press the space bar as soon they saw the letter L, M, or Y. Fifteen percent of the letters were targets.

### Experiment 1 results

- **Exp.1**

Dependent Variable: Reaction Times

No significant main effects nor significant interactions involving exposure.

Task	Signal	Phone position	ON	OFF	p-value
Simple RT	CW	Left	315	316	> 0.82
		Right	323	321	> 0.64
	GSM	Left	311	307	> 0.23
		Right	313	323	> 0.06
Vigilance	CW	Left	286	284	> 0.51
		Right	300	295	> 0.32
	GSM	Left	294	299	> 0.25
		Right	300	295	> 0.55

### Experiment 1 results

- **Exp.1**

Dependent Variable: Reaction Times

No significant main effects nor significant interactions involving exposure.

Task	Signal	Phone position	ON	OFF	p-value
10Choice RT	CW	Left	461	467	> 0.40
		Right	474	469	> 0.51
	GSM	Left	474	475	> 0.82
		Right	483	485	> 0.79
Subtraction	CW	Left	732	736	> 0.79
		Right	750	751	> 0.95
	GSM	Left	770	767	> 0.77
		Right	737	754	> 0.37
Subtraction time	CW	Left	271	269	> 0.87
		Right	276	282	> 0.76
	GSM	Left	297	292	> 0.72
		Right	253	269	> 0.40

### Experiment 2 Vigilance task

- Vigilance task

- Displays showing either
- a single letter
- or a string of 6 letters were presented for 200 ms
- Participants had to press the spacebar any time they saw one of the target letters (target letters being L, M and Y), independently of whether the target was presented as single letter or within a string.
- The inter-stimulus interval randomly varied from 500ms to 3000ms. Each participant was presented with a series of 360 trials (180 single-letters and 180 letter-strings, randomly intermixed) of which 72 (20%) were target trials.

### Experiment 2 Vigilance Task Results (load factor significant)

- Exp.2 VIGILANCE TASK

- (Since the type of phone variable never interacted significantly with the REF the data are collapsed over the type of phone used)
- Dependent Variable: Reaction Times
- No significant main effect nor significant interactions involving exposure.

Task	Phone Position	ON	OFF	p-value
VT single (easy)	Left	304	305	>.70
	Right	302	303	>.74
VT string (Difficult)	Left	508	503	>.69
	Right	504	496	>.38

### Experiment 2 N-back task

- N-back letter task.
- Participants were presented with a long sequence of items (letters and faces - depending on the version of the task) and for each one they had to decide whether or not it was the same as the one presented *N* items earlier in the sequence.
- They pressed either a 'yes' or 'no' key on the computer keyboard as soon as they could.
- Each participant performed a 2-back task and a 3-back task, in which each item was compared with the one presented respectively 2 and 3 positions back. In each version of the task, participants were presented with a sequence of 120 items.
- Target items (i.e., items that were the same as the one presented *n* positions back) occurred 36 times. Each item was shown until a response was given and the following one appeared after 1 second. Each task was preceded by a practice session.

### Experiment 2 N-Back Task Results (load factor significant)

- **Exp.2** 2-3 BACK TASK Letters and Faces

(Since the type of phone variable never interacted significantly with the REF the data are collapsed over the type of phone used)

- Dependent Variable: Reaction Times
- No significant main effect nor significant interactions involving exposure.

Task	Phone Position	ON	OFF	p-value
• 2Back-Letters	Left	923	896	>.58
•	Right	815	823	>.81
• 3Back-Letters	Left	1123	1192	>.30
•	Right	876	906	>.50
• 2Back-faces	Left	857	855	>.93
•	Right	835	856	>.64
• 3Back-faces	Left	1017	1052	>.55
•	Right	930	909	>.61

### Experiment 3 Sternberg Task

- Sternberg task
- *Stimuli.* Black and white drawn pictures (objects and animals) in sequences of 4 or 6. Each sequence of pictures was followed by a display showing either sum or subtraction (1 digit numbers only, e.g., 3 + 4).
- *Procedure.* Each participants was presented with 68 sequences of pictures. A sequence was of either 4 or 6 pictures. Each picture was presented for 1 second. After the presentation of a sequence, a sum or a subtraction was displayed and participants had to say the solution to a microphone. The display disappeared when the response was given. After that, a single test picture was presented, and the task was to decide whether or not that picture appeared in the last presented sequence of pictures. The answer was given by pressing a "Yes" or "No" key on the computer keyboard, and RTs was recorded. After an interval of 4 seconds a new sequence was then shown. Test pictures required a positive response half of times.

### Experiment 3 Sternberg Task Results (load factor significant)

- Sternberg task

(Since the type of phone variable never interacted significantly with the REF the data are collapsed over the type of phone used)

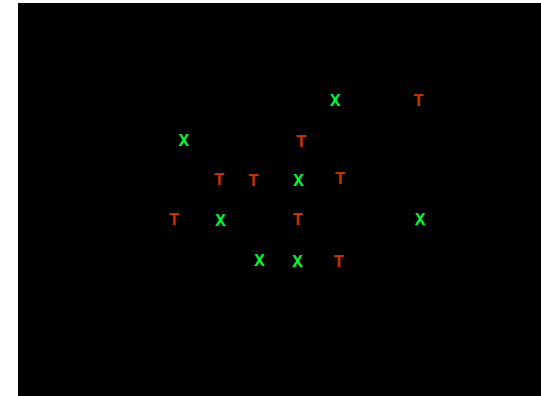
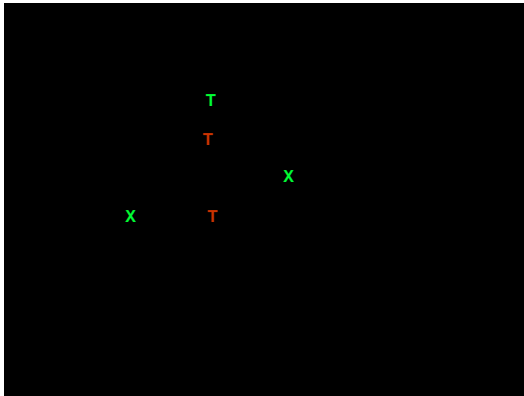
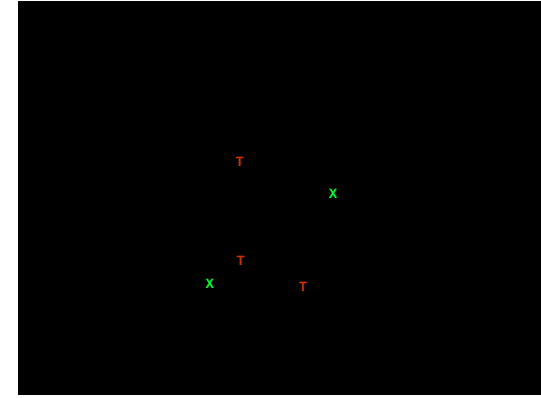
- Dependent Variable: Reaction Times
- No significant main effect nor significant interactions involving exposure.

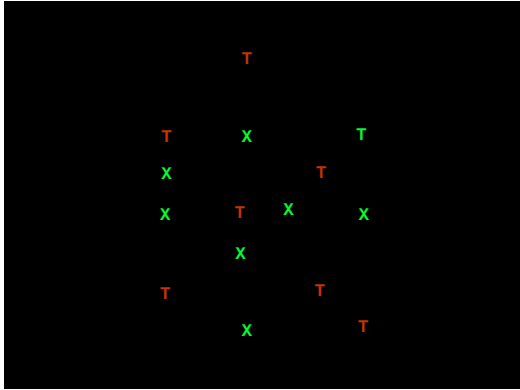
Task	Phone Position	ON	OFF	p-value
• Sternberg -4	Left	1154	1161	>.79
•	Right	1136	1076	<.015
• Sternberg -6	Left	1194	1201	>.78
•	Right	1165	1130	>.15
•				

## Experiment 3 Visual Search Task

### Visual search task

- *Stimuli.* The stimuli were Ts and Xs either in green or brown ink and they subtended an area of  $0.5^\circ \times 0.5^\circ$ .
- *Procedure.* On each display, 5, 15 or 30 coloured letters were presented on a black background. The stimuli were always green and brown Xs and brown Ts (called distractors). A green T - the target - and only one, might be presented and the task of the participants was to decide, as quickly as possible, whether the target was present or not. The response was given by pressing a "yes" key on the computer keyboard if the target was amongst the distractors and a "no" key if it was not.
- A display with a fixation cross preceded each letter display for 500 ms. The letter displays appeared for 3 s or until a response key was pressed. Then, the following trials started after 500 ms. Each participants was presented with a total of 384 trials in three blocks. A practice block of 20 trials preceded the experimental blocks.





### Experiment 3 Visual Search Task Results (load factor significant)

#### Visual search task

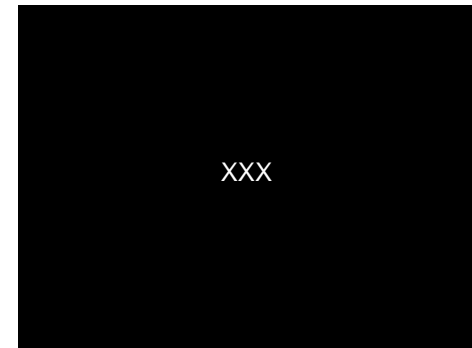
- (Since the type of phone variable never interacted significantly with the REF the data are collapsed over the type of phone used)
- Dependent Variable: Reaction Times
- No significant main effect nor significant interactions involving exposure.

Task	Phone Position	ON	OFF	p-value
VS-5	Left	696	690	>.55
	Right	695	687	>.42
VS-15	Left	917	913	>.76
	Right	900	901	>.93
VS-30	Left	1257	1245	>.59
	Right	1237	1217	>.33

### Experiment 3 Stroop Task

#### Stroop task – numbers

- *Stimuli and Procedure.* On each trial, either a string of digits or a string of Xs was presented at the centre of the screen on a black background. Strings were printed in white. The number of items of each string varied from 1 to 5. Digit strings were repetitions of the same number, which could be any from 1 to 5 (e.g., “5555”, or “33333”). Furthermore, the number of items of each digit string was always different from the number printed in that string (e.g., it could never be “22” or “4444”, etc.).
- The task was to name, as quickly as possible, the number of items on each string. The stimulus display lasted until a verbal response was given and then the following stimulus display appeared after 1 s. Each participant was presented with one block of 120 trials, preceded by an instruction and practice section. Strings of digits and string of Xs were randomly presented with the same frequency, and so was for the number of items on each string.



555

### Experiment 3 Stroop Task Results

- Stroop task – number

- (Since the type of phone variable never interacted significantly with the REF the data are collapsed over the type of phone used)

- Dependent Variable: Reaction Times

Task	Phone Position	ON	OFF	p-value
Stroop-XXX	Left	663	671	>.23
	Right	668	674	>.33
Stroop-Digits	Left	694	697	>.64
	Right	704	701	>.70

### A Bonus: REF Exposure and Subjective Symptoms

- Mean ratings of the five symptoms in Experiments 1-3

	Study 1 (N = 167)		Study 2 (N=159)		Study 3(N=160)	
	Bef.	After p	Bef.	After p	Bef.	After p
• <b>Headache</b>						
• REF	1.25	1.58 <b>0.9</b>	1.25	1.89 <b>0.06</b>	1.19	1.61 <b>0.3</b>
• Sham	1.23	1.54	1.25	1.75	1.20	1.52
• <b>Dizzines</b>						
• REF	1.19	1.59 <b>0.3</b>	1.11	1.59 <b>0.8</b>	1.12	1.66 <b>0.001</b>
• Sham	1.16	1.62	1.13	1.6	1.16	1.49
• <b>Fatigue</b>						
• REF	1.66	1.88 <b>0.02</b>	1.72	2.33 <b>0.3</b>	1.50	2.25 <b>0.6</b>
• Sham	1.58	1.96	1.66	2.18	1.48	2.19
• <b>Itching</b>						
• REF	1.15	1.34 <b>0.5</b>	1.09	1.17 <b>0.06</b>	1.14	1.29 <b>0.6</b>
• Sham	1.13	1.37	1.10	1.31	1.13	1.25
• <b>Warmth on skin</b>						
• REF	1.43	1.93 <b>0.7</b>	1.36	1.81 <b>0.7</b>	1.34	1.84 <b>0.8</b>
• Sham	1.43	1.97	1.40	1.92	1.39	1.71

### Conclusions

- In 3 experiments, we investigated the possible effects of acute exposure to REF generated by a standard mobile phone on human cognition.
- Across six different tasks, neither participants' performance nor subjective symptoms were significantly affected by REF exposure.
- This was true whether participants were exposed to GSM or CW signals and whether the phone was positioned on the left or right side of the head.
- These results are consistent with other recent reports that REF exposure does not seem to affect cognitive performance in human participants (e.g. Haarala et al, 2003, 2004).
- The current results go beyond previous reports, however, in using a wider range of tasks and also showing that REF did not affect cognitive functions under high degrees of cognitive load.
- Furthermore, our study, given the very large samples used, had a much higher degree of statistical power than previous reports (greater than 95% power to reject a false null hypothesis) and therefore provides more secure evidence for the absence of any major effects of acute exposure to mobile phone handsets on human cognitive functioning (within the parameters of the present study).