

The acute effects of exposure to the electromagnetic field emitted by mobile phones on human attention

Nicola Edelstyn^{CA} and Anna Oldershaw

Department of Psychology, University of Keele, Keele, Staffs ST5 5BG, UK

^{CA} Corresponding Author

Received 28 September 2001; accepted 14 November 2001

The aim of our study was to investigate the effects of acute mobile phone exposure on a range of tasks which tapped capacity and processing speed within the attentional system. Thirty-eight healthy volunteers were randomly assigned to either an experimental group which was exposed to a connected mobile phone or a control group in which the mobile phone was switched off. Subjects remained blind to mobile phone status throughout duration of study. The experimental group were exposed to an electromagnetic field emitted by a 900 MHz mobile phone for 30 min. Cognitive performance was assessed at three points (prior to mobile

phone exposure, at 15 and 30 min post-exposure) using six cognitive neuropsychological tests (digit span and spatial span forwards and backwards, serial subtraction and verbal fluency). Significant differences between the two groups were evident after 5 min on two tests of attentional capacity (digit span forwards and spatial span backwards) and one of processing speed (serial subtraction). In all three instances, performance was facilitated following mobile phone exposure. No deficits were evident. These findings are discussed in terms of possible functional and neuroanatomical bases. *NeuroReport* 13:119–121 © 2002 Lippincott Williams & Wilkins.

Key words: Attentional capacity; Electromagnetic field; Processing speed

INTRODUCTION

The proliferation of new media technologies has made them an indispensable aspect of people's lives. Mobile telephone communication is very much a part of this phenomenal growth. In 1999, it was estimated that there were over 470 million mobile phone users around the world, with this number, augmented by the development of third generation systems with multimedia access, expected to rise to a billion by the end of 2002 [1]. The extensive use of mobile phones, both socially as well as in the workplace, and associated reports of headaches, memory loss, depression, feelings of discomfort, warmth behind/around or on the ear and difficulties concentrating [2] have contributed to the public debate about the possible adverse effects on health. These concerns relate to the effects electromagnetic fields (EMF) emitted from the handsets (range 800–1800 MHz) may have on carcinogenicity [3] and neuronal activity [4–6]. Heat generation resulting from a local vasodilatory response [3,7,8] and the inducible form of nitric oxide synthase [4,8,9] are possible causes of the biological effects of electromagnetic exposure. There may also be indirect ways by which health may be affected by mobile phones: evidence suggests that using a mobile phone whilst driving can increase the risk of accidents [10], and health may be adversely affected by the wider environmental impact of mobile phone base stations sited near

homes, schools and places of work which result in whole body exposure to EMF.

Changes in behaviour have also been reported following exposure to electromagnetic fields (EMF) in a small number of animal studies. Two studies by Lai and colleagues found an association between impairments in memory and learning and repeated exposure to 2450 MHz in rodents [11,12], although a recent study [13], which also exposed rodents to EMF, failed to find any significant EMF dependent effects on visuospatial performance. However, the considerably lower intensity radiofrequency fields (900 MHz) used in the latter study may partly account for their results.

An equally small number of studies have investigated the effects of EMF on human cognitive function using actual or simulated mobile phones. Again the results appear equivocal. Preece and colleagues reported decrements in working memory, recognition memory and attention in sixteen healthy volunteers following acute exposure to a 50 Hz static magnetic field [14]. However, later studies by Preece and others have reported facilitatory effects on processing speed i.e. faster reaction times, on a range of tasks tapping attentional and working memory processes [15–17].

The current study was designed to investigate the effects of mobile phone exposure on a processing speed and capacity within the attentional system.

MATERIALS AND METHODS

Participants: Thirty-eight psychology undergraduates took part in the study, 26 were regular mobile phone users. Mean age was 21 (range 20–22) years. Subjects completed a questionnaire which was used to exclude participants who were left handed, had a neurological or psychiatric history, on regular medication, had consumed excessive amounts of alcohol or caffeine during the previous 24 h, or had less sleep than usual.

Design: Suitable participants were randomly allocated to either the experimental phone-connected or control phone-nonconnected group. They were instructed to hold the mobile phone (900 MHz; specific-energy absorption rate 1.19/kg of exposed body tissue) [18] with their left hand to their left ear for 30 min. Subjects were unaware which group they were in (the mobile phone display was covered).

Cognitive neuropsychological tests were performed at three points during study: an initial set of baseline data was collected prior to mobile phone introduction; two more sets of data were collected 15 min and again 30 min following mobile phone exposure. Neuropsychological testing lasted ~8 min. The neuropsychological tests broadly fell into two categories, which, amongst other functions, assessed attentional capacity and processing speed. Attentional capacity was measured using four span tests: digit span forwards (DSF) and digit span backwards (DSB), spatial span forwards (SSF) and spatial span backwards (SSB). Both digit span forwards and digit span backwards consisted of seven pairs of random number sequences which were read aloud at a rate of 1/s. Pairs of number sequences ranged from three to nine digits. Participants were required to immediately repeat the same sequence in either the same (i.e. forwards) or reverse (i.e. backwards) order. Testing was concluded when the subject either failed both pairs, or repeated the final nine digit sequences correctly. Spatial span forwards and spatial span backwards tests followed the same format as the digit span tasks in terms of exposing participants to increasingly larger amounts of information. Estimation of spatial span involved use of nine white cubes fastened in a random order to a board. During each trial, the blocks were tapped in a prearranged sequence (one cube/s), which the participant was required to repeat immediately in either the same (i.e. forwards) or reverse (i.e. backwards) order. Pairs of sequences, which ranged from three to nine cubes were administered. Testing was concluded when the subject either failed both pairs, or repeated the nine cube sequence correctly.

Processing speed was examined using tests of serial subtraction and verbal fluency. The serial subtraction task required participants to perform a series of mental subtractions, each successive subtraction being made from the product of the previous one e.g. taking 7 away: 100, 93, 86, 79. Each participant was given a 30 s time limit. Performance indicator was the accuracy rates. The verbal fluency task consisted of subjects generating as many items as possible beginning with either F, A or S within a 60 s period. Total number of correctly generated words (minus inclusion of repetitions, non-words or foreign words) was used as the performance measure.

The same tasks (in terms of format but not test stimuli) were administered at each of the three assessment points. Order of test presentation was counterbalanced across participants.

RESULTS

Both groups were matched in terms of baseline performance measures, therefore any differences found subsequently were attributed to the introduction of the mobile phone (connected *vs* unconnected). Differences in mean scores between baseline and 15 min and between 15 and 30 min on each of the six tasks were analysed using two-way repeated ANOVA with one between-subject factor (mobile phone connected or unconnected) and one within-subjects factor (score difference between combination of test runs). Significant main effects were found for digit span forward ($F(1,37)=17.05$, $p<0.000$), spatial span backwards ($F(1,37)=5.91$, $p<0.017$) serial subtraction subtests ($F(1,37)=3.95$, $p<0.05$), spatial span forward ($F(1,37)=12.37$, $p<0.000$) and verbal fluency subtests ($F(1,37)=5.43$, $p<0.006$). An interaction between group and exposure duration was found on two subtests: digit span forward ($F(1,37)=3.54$, $p<0.032$) and serial subtraction ($F(1,37)=3.68$, $p<0.028$).

Further analyses were performed to examine the locus of the effect for these interactions. No significant simple main effects were found for the unconnected group. However, significant simple main effects were evident for the connected group on digit span forward ($F(2,74)=3.24$, $p<0.05$) and spatial span backward ($F(2,74)=6.10$, $p<0.05$), and these were evident after 15 min exposure (digit span forward: $F(1,36)=6.5$, $p<0.05$; spatial span backward: $F(1,36)=6.5$, $p<0.05$).

DISCUSSION

We have shown that, when considered as a group, healthy volunteers exposed to a mobile phone EMF for 15 min are more likely than non-exposed controls to show improved immediate verbal memory capacity, immediate visuospatial working memory capacity and sustained attention, as evident from their performance on forwards digit span, backwards spatial span and serial subtraction tasks, respectively. On all three tasks, these improvements were evident following 15 min exposure, which suggests that the biological effects of EMF are fast acting. A similar time period was noted by Preece *et al.* [19].

Our study is significant in that we have demonstrated facilitated processing in the two basic dimensions of attention [20]: capacity i.e. how much the attentional system can process (forwards digit span and backwards spatial span) as well as in processing speed i.e. how fast the attentional system operates (serial subtraction). Previous studies had noted decrements in capacity [14] or facilitation in processing speed [17,21].

Koivisto *et al.* [17] proposed that EMF exposure affects performance on tasks dependent on attentional processes linked to prefrontal function. However, it is areas of the parietal and temporal lobe, not the prefrontal cortex, which are closest to the antenna. If, as has been suggested, the effects of EMF exposure is mediated by a localised

vasodilatory response, changes in cognitive processes associated with these areas rather than the prefrontal cortex would be predicted.

We believe that our findings can be interpreted in the context of changes in activity in brain areas more proximal to the antenna and therefore subject to a localised vasodilatory response. For instance, digit span forwards requires the retention and immediate recall of increasing amounts of verbal information. Inner speech i.e. the mental repetition of the digit sequences, is a key component in this. A number of recent functional neuroimaging studies of normal volunteers have implicated language areas located in the left inferior frontal gyrus, left superior temporal gyrus and lateral inferior parietal cortex, brain areas more proximal to the phone's antenna, in the generation and use of inner speech [22,23]. It is interesting to speculate why forwards but not backwards digit span was selectively facilitated in the reported study. Forwards digit span is a reasonably straightforward test of attentional capacity, whereas backwards digit span involves more attentional resources in terms of both holding the information as well as reordering it. The additional processing presumably requires additional activity in other brain areas unaffected by EMF exposure for instance the prefrontal cortex.

Studies of animals and brain-injured patients have shown that the parietal cortex is involved in aspects of spatial processing, attentive behaviour and orienting [24] (for review see [25]). In particular, neurons in the parietal cortex play a key role in coding the locations of objects. Given the relative proximity of the parietal lobe to the mobile phone's antenna, it is perhaps not surprising to find an effect on spatial processing. However, this was only evident in the backwards spatial span task. This finding may reflect changes in activity which underpins processes concerned with the orienting aspects of the task rather than spatial capacity *per se*. In contrast to the reported facilitatory effects in healthy volunteers, studies of the effects of EMF on spatial processing in rodents have found deficits in spatial learning. However, these animals were exposed to relatively high doses of whole body radiation over an increased length of time. It is possible that the effects of chronic exposure may be more related to disruption of processes involved in memory (consolidation, storage and/or retrieval) whereas the acute changes brought about by short-term exposure may be mediated by changes within the attentional system (spatial orienting, vigilance). However, since only spatial learning in rodents was investigated, it is difficult to interpret the reported findings further [11–13]. In keeping with the findings of Preece *et al.* [15], evidence of improved processing speed was apparent on the test of serial subtraction. As with backwards digit span and forwards spatial span, this may in part be underpinned by an increased ability to filter out distracting information and

focus attentional resources on the mental task. Functional imaging studies using PET have implicated the Pulvinar nucleus in this process [26], which, although a subcortical structure, is located within the region of the antenna and therefore potentially subject to the effects of local thermal heating. Finally, failure to find an effect on verbal fluency may be attributable to the increased demands this task places on frontal function in terms of the ability to monitor and modify output in the light of feedback [20].

In conclusion, we have demonstrated a facilitatory effect on a range of cognitive functions in healthy human volunteers using an EMF emitted by a mobile phone. The changes in function are relatively fast acting and attempts have been made to relate them to specific cortical areas being irradiated.

REFERENCES

1. Department of Health. www.doh.gov.uk/mobilephones/mobile-phones.htm.
2. Sandstrom M, Wilen J, Ofstedal G and Mild KH. *Occup Med* **51**, 25–35 (2001).
3. Blettner M and Berg G. *Acta Oncol* **39**, 927–930 (2000).
4. Kavaliers M, Choleris E, Prato FS and Ossenkopp K-P. *Brain Res* **809**, 50–57 (1998).
5. Scott IR, Wood SJ and Tattersall JEH. *Proceedings of Bioelectromagnetics Society 1998; 20th Annual Meeting*, St. Petersburg, Florida, USA.
6. Krause CM, Sillanmäki L, Koivisto M *et al.* *Neuroreport* **11**, 761–764 (2000).
7. Mickley GA and Cobb BL. *Physiol Behav* **63**, 855–865 (1998).
8. Paredi P, Kharitonov SA, Hanazawa T and Barnes PJ. *Laryngoscope* **111**, 159–162 (2001).
9. Yoshikawa T, Tanigawa M, Tanigawa T *et al.* *Pathophysiology* **7**, 131–135 (2000).
10. Briem V and Hedman LR. *Ergonomics* **38**, 2536–2562 (1995).
11. Lai H, Horita A and Guy AW. *Bioelectromagnetics* **15**, 95–104 (1994).
12. Wang BM and Lai H. *Bioelectromagnetics* **21**, 52–56 (2000).
13. Sienkiewicz ZJ, Blackwell RP, Haylock RGE *et al.* *Bioelectromagnetics* **21**, 151–158 (2000).
14. Preece AW, Wesnes KA and Iwi GR. *Int J Radiat Biol* **74**, 463–470 (1998).
15. Preece AW, Iwi GR, Davies-Smith K *et al.* *Int J Radiat Biol* **75**, 447–456 (1999).
16. Lee TMC, Ho SMY, Tsang LYH *et al.* *Neuroreport* **12**, 729–731 (2001).
17. Koivisto M, Krause CM, Revonsuo A *et al.* *Neuroreport* **11**, 1641–1643 (2001).
18. Fairley P. *Sunday Times* **11**, 16–17 (2001).
19. Preece AW, Iwi GR, Davies-Smith K *et al.* www.bris.ac.uk/Depts/Medphys/research/biophys/phone/phone.htm (2001).
20. Lezak MD. *Neuropsychological Assessment*. Oxford: OUP; 1995.
21. Preece AW. *Neuroreport* **11**(2), i (2000).
22. Herholz K, Thiel A, Weinhard K *et al.* *Neuroimage* **3**, 185–194 (1996).
23. Sadato N, Yonekura Y, Yamada H *et al.* *J Comput Assist Tomogr* **22**, 945–952 (1998).
24. Wurtz RH, Goldberg ME and Robinson DL. *Sci Am* **246**, 124–135 (1982).
25. Gazzaniga MS, Ivry RB and Magnum GR. *Cognitive Neuroscience. The Biology of the Mind*. New York: Norton and Co: 1998, pp. 207–245.
26. La Berge D. *J Cogn Neurosci* **2**, 358–372 (1990).