

Short-Term Exposure to Mobile Phone Base Station Signals Does Not Affect Cognitive Functioning or Physiological Measures in Individuals Who Report Sensitivity to Electromagnetic Fields and Controls

Stacy Eltiti,¹ Denise Wallace,² Anna Ridgewell,² Konstantina Zougkou,² Riccardo Russo,² Francisco Sepulveda,² and Elaine Fox^{2*}

¹Rosemead School of Psychology, Biola University, La Mirada, California

²Department of Psychology, University of Essex, Colchester, UK

Individuals who report sensitivity to electromagnetic fields often report cognitive impairments that they believe are due to exposure to mobile phone technology. Previous research in this area has revealed mixed results, however, with the majority of research only testing control individuals. Two studies using control and self-reported sensitive participants found inconsistent effects of mobile phone base stations on cognitive functioning. The aim of the present study was to clarify whether short-term (50 min) exposure at 10 mW/m² to typical Global System for Mobile Communication (GSM) and Universal Mobile Telecommunications System (UMTS) base station signals affects attention, memory, and physiological endpoints in sensitive and control participants. Data from 44 sensitive and 44 matched-control participants who performed the digit symbol substitution task (DSST), digit span task (DS), and a mental arithmetic task (MA), while being exposed to GSM, UMTS, and sham signals under double-blind conditions were analyzed. Overall, cognitive functioning was not affected by short-term exposure to either GSM or UMTS signals in the current study. Nor did exposure affect the physiological measurements of blood volume pulse (BVP), heart rate (HR), and skin conductance (SC) that were taken while participants performed the cognitive tasks. Bioelectromagnetics 2009.

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INTRODUCTION

A key area of concern regarding the impact of mobile phone technology on human health is the possibility that it may impair cognitive function. There are a group of people who claim that they are sensitive to the electromagnetic fields (emf) emitted by mobile phones and their associated base stations and this condition has been labeled electromagnetic hypersensitivity (EHS). However, because of uncertainty regarding whether the symptoms are due to emf, it has been recommended that this condition be termed idiopathic environmental intolerance with attribution to electromagnetic fields (IEI-EMF) [Hansson Mild et al., 2006]. Among the most commonly reported symptoms by this group are difficulties in concentration and memory [e.g., Hillert et al., 1999; Eltiti et al., 2007a].

In spite of many anecdotal reports of such problems, results from laboratory-based studies investigating mobile phone exposure and cognitive

functioning have been mixed. Early findings reported enhanced attention and memory skills [e.g., Preece et al., 1999; Koivisto et al., 2000a,b], while more recently impaired cognitive performance has been reported [Maier et al., 2004; Keetley et al., 2006]. Many other studies have reported no effect of mobile phone emf on cognitive functioning [e.g., Haarala et al.,

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*Correspondence to: Elaine Fox, Department of Psychology, University of Essex, Wivenhoe Park, Colchester CO4 3SQ, UK. E-mail: efox@essex.ac.uk

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2003, 2005]. In particular, recent studies with larger sample sizes have shown no effect of mobile phone emissions on tests of attention [Russo et al., 2006; Unterlechner et al., 2008] and memory [Cinel et al., 2008] nor mobile phone base station emissions on general cognitive functioning [Riddervold et al., 2008]. A meta-analysis of 10 studies showed that exposure to mobile phone emissions may facilitate attention, have inconsistent effects on working memory, and have no effect on simple reaction, choice reaction time, vigilance, or sentence verification tasks [Barth et al., 2008]. It is important to note, however, that these studies did not include sensitive individuals, that is, individuals who believed they were sensitive to emf. Therefore, it is possible that impaired cognitive functioning might be observed with such sensitive individuals.

One unpublished study [Zwamborn et al., 2003] tested sensitive and control individuals under double-blind conditions to determine whether exposure to 900 MHz Global System for Mobile Communication (GSM), 1800 MHz GSM, and 2100 MHz Universal Mobile Telecommunications System (UMTS) base station-like signals affected performance on a range of cognitive tasks: object categorization, memory comparison, visual selective attention, and dual tasking. The results for these tests were inconsistent—sometimes indicating enhanced performance, and at other times indicating impaired performance between active and sham conditions. Furthermore, if the appropriate statistical adjustments were made to the alpha level for multiple comparisons, none of the findings remained significant. In an attempted replication of the Zwamborn et al. [2003] study, Regel et al. [2006] could find no difference in cognitive functioning between sham and UMTS base station exposures for either sensitive or control individuals.

Given the small number of studies specifically investigating IEI-EMF individuals, the current study was conducted to further examine whether, under double-blind conditions, exposure to typical GSM and UMTS base station signals affect cognitive functioning in sensitive and control individuals. Cognitive functioning was measured using digit symbol substitution (DSST), forward digit span (DS), and mental arithmetic (MA) tasks. The DSST measures attention and perceptual-motor speed [e.g., Ward, 2004; Keetley et al., 2006], the DS is a good measure of immediate memory [Russell, 1997], and MA has been shown to be a cognitively demanding task requiring the central executive component of working memory [DeStafano and LeFevre, 2004]. In addition, physiological measurements of blood volume pulse (BVP), heart rate

(HR), and skin conductance (SC) were taken while participants performed the cognitive tasks. It was hypothesized that sensitive participants would have impaired performance on cognitive tests, that is, poorer memory and concentration during the GSM and UMTS exposures compared to sham exposure; whereas control participants would not be affected by exposure to either the GSM or UMTS signals. In addition, it was hypothesized that if sensitive individuals found the cognitive tasks more difficult during the active compared to sham condition, there would be a corresponding increase in their physiological measurements (e.g., increased HR and SC).

METHODS

Participants

Forty-four self-reported sensitive individuals and 115 control individuals took part in this study. Sensitive participants explicitly associated their current health problems with exposure to emf from mobile phones and/or their associated base stations, whereas control participants did not report any health problems from emf exposure. For further information on the recruitment and selection of sensitive and control participants, see Eltiti et al. [2007b]. Due to experimental error one control participant received two sham and one GSM exposure; therefore, the data for that participant were excluded from further analysis. It has been well documented that cognitive functioning (especially memory and perceptual speed) decreases with age [e.g., Earles et al., 1997]. In the present study, the sensitive group (Mean (M) = 46.14, standard deviation (SD) = 13.2) was significantly younger than the control group (M = 54.03, SD = 15.4; $t(156) = -2.99$, $P < 0.01$). This means that age could act as a confounding variable and any difference in performance between the groups would be masked by an age effect. The best way to control for this is to use age-matched controls. Therefore, only the data for 44 age-matched control participants (sensitive M = 46.1, SD = 13.3; control M = 46.1, SD = 13.2) were analyzed together with the data for the sensitive participants. Given the large sample size of control participants, data from the 114 controls were analyzed separately to determine if emf exposure affects cognitive functioning in control individuals. There were relatively equal numbers of males and females in each group (Sensitive: male 59.1%; Control: male 54.5%; $\chi^2(1) = 0.19$, $P > 0.05$). All testing was conducted at the Electromagnetics and Health Laboratory at the University of Essex, UK. Participants were reimbursed for food and travel expenses and paid

£20 for participation. This study was approved by the University of Essex ethics committee.

Design

The study was a double-blind provocation study in which participants were exposed to three conditions: GSM, UMTS, and sham. This involved four testing sessions, which occurred at least 1 week apart at approximately the same time of day (± 3 h). During session 1 baseline measures of cognitive functioning were taken. Participants completed the Wechsler Adult Intelligence Scale-Revised (WAIS-R) Digit Span forward and backwards test, the DSST, and DS task. During sessions 2, 3, and 4 participants performed 20 min of relaxation (low load condition), 20 min of MA (high load condition) and then completed the DSST and DS. Order of low versus high load and DSST versus DS were counterbalanced across participants. The between-participant factor was group (sensitive vs. control). The dependent variables for cognitive functioning were the number of symbols correctly completed in the DSST and percentage of correct scores for the DS and MA. Different versions of all the tests were developed and used to minimize practice effects. The *M* and *SD* were the dependent variables for the physiological measurements of BVP, HR, and SC.

Exposure System

The GSM signal was a combined signal of both the 900 and 1800 MHz frequency bands, each with a power flux density of 5 mW/m^2 , resulting in a combined power flux density of 10 mW/m^2 over the area where the participant was seated. The UMTS signal had a frequency of 2020 MHz with a power flux density of 10 mW/m^2 over the area where the participant was seated. In 2002 the National Radiological Protection Board (currently known as the Health Protection Agency) in the United Kingdom published a report, which measured the power density from mobile phone base stations at 17 sites and 118 locations [Mann et al., 2002]. In general, the power density was reported to range from $10 \mu\text{W/m}^2$ to 1 mW/m^2 with the highest power density being 8.3 mW/m^2 . Thus, the power density of 10 mW/m^2 was used, as it is comparable to the maximum power density an individual would be exposed to in the real world. During the sham condition nothing was transmitted, therefore the power was nil. The power density was calibrated every 6 months and was found not to vary greater than ± 3 dB of tolerance. Double-blinding and counterbalancing of exposures were controlled by the exposure control computer. A full description of the exposure system can be found in Eltiti et al. [2007b]. In addition, a copy of the technical reference manual is available upon request.

Materials

Different versions of the MA, DSST, and DS tasks were developed. For the MA task, two sets of two digit numbers were randomly chosen with approximately half of them being addition and half subtraction equations. Three different versions of this task were developed. There were 12 practice trials in which participants added and subtracted one digit numbers followed by 187 experimental trials. The range of possible scores was from 0 to 187. The MA task took 20 min to complete. Four versions of the DSST were constructed using different symbols to correspond to the numbers 1–9. [A copy of the symbols used is available upon request.] No symbols were repeated and the range of possible scores was from 0 to 118. Likewise, four different versions of the DS were created, each trial consisting of seven randomly selected one digit numbers from 1 to 9 without repetition. There were 15 trials and answers were marked correct if the digit appeared in the correct position. The range of possible scores was from 0 to 105. Initially, the DS task required participants to recall six digits per trial; however, inspection of accuracy rates for the first five participants revealed that this task was too easy ($M = 91.4\%$). In order to compensate for this, the number of digits to be recalled per trial was increased to seven for the remaining participants ($M = 79.3\%$). Therefore, the DS data for the first five participants were not included in the analysis. All responses were made using paper and a nonmetallic pen. Physiological measurements were recorded using a ProComp Infiniti 8 channel encoder with Biograph Infiniti software (Plattsburgh, NY) run on a Dell Latitude notebook (Dublin, Ireland). Physiological measurements were taken using three small cuffs placed on the participant's nondominant hand. Detailed information regarding the physiological equipment and measurements are reported in Eltiti et al. [2007b].

Procedures

Testing took place on four separate occasions at least 1 week apart, with one participant tested at a time. During Session 1, as part of the background information taken, the WAIS-R digit forward and backward span test was administered to obtain baseline measures of short-term memory. Participants then took part in an open provocation test in which they knew when the base station was “on” or “off” and if it was “on” whether it was the GSM or UMTS signal. Participants were asked to complete visual analogue scales (VAS) measuring subjective well-being every 5 min and record any symptoms they experienced. [Results for VAS and symptoms are reported in Eltiti et al., 2007b.] At the end

of the open provocation, participants completed the DSST followed by DS or vice versa. For the DSST participants were given 90 s to complete as many symbols as possible. For the DS, participants were shown seven one-digit numbers. Each digit appeared for 1 s and participants were then given 10 s to write down the digits in the exact same order as they appeared, always starting with the first digit. Physiological measurements of BVP, HR, and SC were taken continuously during the open provocation, DSST, and DS tasks. Participants then completed a quick double-blind test in which they judged whether the base station was “on” or “off.” Session 1 took ~3 h to complete.

Sessions 2, 3, and 4 were all double-blind, but this time the three exposures were spread out over the three sessions. For example, session 2 could have been GSM, session 3 sham, and session 4 UMTS, or they could occur in a different order. The duration of the exposure was 50 min, during which time physiological measurements were taken continuously. For the first 20 min participants either engaged in the low load task (watching the “Blue Planet” video) followed by 20 min of the high load task (MA) or vice versa. During the MA, participants were given 5 s to complete each equation. During both low and high load tasks, participants completed VAS every 5 min and recorded any symptoms they experienced. Participants then performed the DSST followed by the DS, or vice versa and made a judgement as to whether the base station was “on” or “off.” Sessions 2, 3, and 4 each took ~1.5 h to complete. Further details about the procedures, laboratory, exposure system, and physiological system, as well as the overall analysis of measures of well-being and on/off judgements are reported in Eltiti et al. [2007b].

RESULTS

Baseline Measures

t-Test analysis revealed no difference between the groups in their performance on the baseline measurements of WAIS-R forward span, WAIS-R backward span, total WAIS-R digit span score, DSST, or DS tasks. See Table 1 for means, standard errors, and *P*-values. In addition, 2 (group: sensitive, matched control) × 2 (type of test: open provocation, double-blind) ANOVAs were performed for the DSST and DS tasks to determine if sensitive and matched control participants performed the same during the open provocation and double-blind tests. The results for both the DS and DSST showed a main effect of type of test, $F(1,76) = 34.10$, $P < 0.001$; $F(1,86) = 19.11$,

TABLE 1. Means, Standard Errors, and *P*-Values for Baseline Measures of Cognitive Ability for Sensitive and Matched Control Participants

| Cognitive task | Sensitive, <i>M</i> (SE) ^a | Control, <i>M</i> (SE) | Sensitive vs. control, <i>P</i> |
|----------------|---------------------------------------|------------------------|---------------------------------|
| WAIS forward | 8.51 (0.3) | 8.27 (0.4) | 0.625 |
| WAIS backward | 7.29 (0.3) | 7.51 (0.4) | 0.673 |
| WAIS total | 15.80 (0.6) | 15.78 (0.7) | 0.979 |
| Digit span | 73.13 (3.5) | 80.31 (2.7) | 0.111 |
| Digit symbol | 44.89 (2.0) | 47.59 (1.7) | 0.306 |

^aMeans and standard errors.

$P < 0.001$, respectively, with better performance during the double-blind ($M = 83.4$; 49.04) compared to open provocation test ($M = 76.7$; 46.24). This indicates that there was a practice effect for these tasks and all participants’ performance improved with subsequent testing. The main effect of group for the DS and DSST both showed a trend towards significance, $F(1,76) = 3.48$, $P = 0.066$; $F(1,86) = 2.64$, $P < 0.11$, with better performance among control participants ($M = 83.7$; 49.77) compared to sensitive participants ($M = 76.4$; 45.50). The interaction between group and type of test was not significant for the DS task, $F(1,76) < 1$, $P = 0.915$; however, it was significant for the DSST task, $F(1,86) = 5.97$, $P = 0.017$. Independent samples *t*-test showed that there was no difference between the groups during the open provocation test, $t(86) = 1.03$, $P = 0.306$, and no difference during the double-blind test, $t(86) = 2.10$, $P = 0.039$, once a Bonferroni correct for multiple comparisons was applied, $\alpha = 0.025$. Alpha values for Bonferroni corrections were obtained by taking 0.05/number of comparisons.

Cognitive Measures

Controls only. Separate repeated measures ANOVAs were performed on the percentage correct scores for the DS and MA tasks and the number of correct scores for the DSST, for the full compliment of 114 control participants to determine the effect of exposure on performance. The results for these tests were not significant, F 's (2,226) < 1.75 , P 's > 0.18 . In other words, control participants’ performance on the cognitive tasks was not affected by emf exposure.

Sensitive and matched controls. Since we were unable to test our target of 264 participants we were not able to completely counterbalance exposure order. Thus, exposure order was included in the analysis to determine if this had any affect on participants’ performance. The results for the analysis based on all

six exposure orders were virtually identical to those when order was collapsed based on which exposure participants received first. Thus, for clarity the results presented are based on the order of exposure that participants received first. In other words, the data for participants who received sham, GSM, and UMTS was combined with those that received sham, UMTS, and GSM to form a sham first group. Separate 2 (group: sensitive, matched control) \times 3 (condition: sham, GSM, UMTS) \times 3 (order: sham first, GSM first, UMTS first) mixed ANOVAs were performed on the percentage correct scores for the DS and MA tasks and the number of correct scores for the DSST, to determine if type of exposure affected cognitive performance while controlling for age. See Table 2 for means, standard errors, and P -values. There was no between-group difference for DSST, $F(1,82) = 4.85$, $P = 0.03$, after applying the Bonferroni correction for multiple tests, $\alpha < 0.017$. None of the other main effects were significant, F 's < 1.96 , P 's > 0.14 . There was a significant condition by order interaction for the DSST, $F(4,164) = 4.16$, $P = 0.003$, and MA tasks, $F(4,164) = 8.86$, $P = 0.001$, which did not interact with group. Overall, performance was significantly worse during each first exposure compared to subsequent exposures. For example, during the MA task participants who received the sham exposure first performed better during the GSM exposure compared to sham. None of the other interactions were significant, F 's < 2.21 , P 's > 0.12 .

Physiological Measurements

M and SD for BVP, HR, and SC were calculated for the DSST, DS, and MA tasks. The data for BVP (M and SD) and SC (M and SD) and the HR (SD) were skewed in the positive direction. Thus, the data were transformed using the square root function for BVP (SD) and SC (M and SD) and the logarithmic function for the HR (SD). BVP (M) did not lend itself to transformation; therefore these data were not analyzed. Mean HR data were not skewed so analysis was performed on the original data. The data were analyzed using 3 (condition: sham, GSM, UMTS) \times 2 (group: sensitive, control) mixed ANOVAs. See Table 3 for means, standard errors, and P -values. During all three cognitive tasks, F 's(1,86) > 7.14 , P 's < 0.005 , there were significant between-group differences, with sensitive individuals having a higher SC (M) than controls even after applying the Bonferroni correction, $\alpha < 0.01$, whereas for the SC (SD), the between-group differences, F 's(1,86) < 6.74 , P 's > 0.01 , were not significant after applying the Bonferroni correction, $\alpha < 0.01$. None of the other main effects or interactions were significant, F 's < 1.51 , P 's > 0.22 .

TABLE 2. Means, Standard Errors, and P -Values for the Cognitive Tasks by First Exposure by Condition for Sensitive Versus Control Participants

| Cognitive task | Sham | | | GSM | | | UMTS | | | Condition by first exposure, P | Group by first exposure, P | Condition by first exposure, P |
|-------------------|----------------------------------|-------------------|------------|---------------------|-------------------|------------|---------------------|-------------------|-------|----------------------------------|------------------------------|----------------------------------|
| | Sensitive, M (SE) ^a | Control, M (SE) | P | Sensitive, M (SE) | Control, M (SE) | P | Sensitive, M (SE) | Control, M (SE) | P | | | |
| Digit span | 82.6 (2.7) | 87.4 (2.7) | 77.6 (2.8) | 87.0 (2.8) | 79.0 (2.9) | 87.1 (2.9) | 0.146 | 0.089 | 0.569 | 0.194 | 0.373 | 0.117 |
| Digit symbol | 46.2 (2.1) | 51.9 (2.1) | 45.9 (2.1) | 51.8 (2.1) | 46.3 (2.0) | 52.2 (2.0) | 0.642 | 0.030 | 0.330 | 0.907 | 0.003 | 0.440 |
| Mental arithmetic | 69.5 (3.1) | 76.2 (3.1) | 69.9 (3.1) | 77.4 (3.2) | 67.8 (3.1) | 78.1 (3.1) | 0.414 | 0.105 | 0.886 | 0.366 | 0.001 | 0.177 |

P -values in bold are significant after applying the Bonferroni correction for multiple tests ($P < 0.017$).

^aMeans and standard errors.

TABLE 3. Means, Standard Errors, and P-Values for the Mean (M) and Standard Deviation (SD) for Blood Volume Pulse (BVP), Skin Conductance (SC), and Heart Rate (HR) During the Cognitive Tasks by Type of Exposure for Sensitive and Control Participants

| Cognitive task | Sham | | GSM | | UMTS | | Condition, <i>P</i> | Condition by group, <i>P</i> | Group, <i>P</i> |
|--------------------------------|---------------------------------------|------------------------|--------------------------|------------------------|--------------------------|------------------------|---------------------|------------------------------|-----------------|
| | Sensitive, <i>M</i> (SE) ^a | Control, <i>M</i> (SE) | Sensitive, <i>M</i> (SE) | Control, <i>M</i> (SE) | Sensitive, <i>M</i> (SE) | Control, <i>M</i> (SE) | | | |
| Digit span ^c | | | | | | | | | |
| BVP <i>M</i> ^b | 34.30 (0.05) | 34.40 (0.07) | 34.27 (0.10) | 34.48 (0.08) | 34.35 (0.07) | 34.46 (0.08) | N/A | N/A | N/A |
| BVP SD | 2.08 (0.24) | 1.85 (0.24) | 1.97 (0.24) | 1.72 (0.23) | 1.81 (0.21) | 2.00 (0.26) | 0.747 | 0.250 | 0.726 |
| SC <i>M</i> | 5.99 (0.65) | 4.58 (0.42) | 6.04 (0.61) | 4.23 (0.41) | 6.58 (0.63) | 4.74 (0.62) | 0.454 | 0.634 | 0.009 |
| SC SD | 0.38 (0.04) | 0.30 (0.04) | 0.39 (0.05) | 0.26 (0.03) | 0.40 (0.04) | 0.32 (0.05) | 0.461 | 0.738 | 0.041 |
| HR <i>M</i> | 72.98 (1.48) | 74.00 (1.77) | 73.73 (1.54) | 73.45 (1.70) | 72.93 (1.41) | 73.32 (1.64) | 0.815 | 0.694 | 0.858 |
| HR SD | 6.84 (1.10) | 5.96 (0.59) | 6.55 (0.84) | 7.44 (0.86) | 6.90 (0.96) | 6.40 (0.90) | 0.278 | 0.279 | 0.622 |
| Digit symbol ^c | | | | | | | | | |
| BVP <i>M</i> | 34.31 (0.05) | 34.40 (0.07) | 34.23 (0.12) | 34.47 (0.08) | 34.34 (0.07) | 34.45 (0.08) | N/A | N/A | N/A |
| BVP SD | 1.97 (0.26) | 1.55 (0.20) | 1.88 (0.23) | 1.46 (0.18) | 2.04 (0.30) | 1.65 (0.19) | 0.596 | 0.892 | 0.219 |
| SC <i>M</i> | 6.01 (0.61) | 4.48 (0.42) | 6.05 (0.57) | 4.13 (0.40) | 6.54 (0.64) | 4.70 (0.62) | 0.491 | 0.724 | 0.004 |
| SC SD | 0.32 (0.05) | 0.28 (0.05) | 0.34 (0.04) | 0.22 (0.02) | 0.35 (0.04) | 0.28 (0.04) | 0.462 | 0.741 | 0.091 |
| HR <i>M</i> | 74.13 (1.79) | 75.17 (1.77) | 75.01 (1.78) | 75.15 (1.72) | 74.23 (1.57) | 74.40 (1.55) | 0.671 | 0.835 | 0.839 |
| HR SD | 5.28 (0.85) | 4.82 (0.71) | 6.47 (1.20) | 5.46 (0.79) | 6.40 (1.08) | 4.75 (0.70) | 0.636 | 0.470 | 0.659 |
| Mental arithmetic ^c | | | | | | | | | |
| BVP <i>M</i> | 34.30 (0.05) | 34.40 (0.07) | 34.29 (0.11) | 34.47 (0.08) | 34.34 (0.07) | 34.44 (0.08) | N/A | N/A | N/A |
| BVP SD | 2.50 (0.28) | 2.34 (0.25) | 2.39 (0.24) | 2.02 (0.23) | 2.32 (0.24) | 2.41 (0.27) | 0.361 | 0.226 | 0.664 |
| SC <i>M</i> | 5.92 (0.58) | 4.58 (0.37) | 5.85 (0.49) | 4.15 (0.36) | 6.53 (0.60) | 4.75 (1.59) | 0.260 | 0.609 | 0.007 |
| SC SD | 0.61 (0.07) | 0.51 (0.07) | 0.70 (0.07) | 0.46 (0.05) | 0.68 (0.06) | 0.49 (0.07) | 0.723 | 0.317 | 0.011 |
| HR <i>M</i> | 75.06 (1.61) | 75.87 (1.80) | 76.12 (1.46) | 76.07 (1.78) | 75.35 (1.73) | 75.62 (1.71) | 0.642 | 0.851 | 0.880 |
| HR SD | 6.58 (0.89) | 5.84 (0.47) | 6.25 (0.60) | 7.01 (0.76) | 6.89 (0.69) | 6.61 (0.66) | 0.319 | 0.415 | 0.800 |

P-values in bold are significant after applying the Bonferroni correction for multiple tests within each cognitive task ($P < 0.01$).

^aMeans and standard errors for original untransformed data.

^bBVP Mean did not lend itself to transformation; therefore, these data were not analyzed.

^cNonparametric statistics was also performed on the untransformed data with virtually the same result (copies of this analysis is available upon request).

DISCUSSION

Overall, sensitive participants had a significantly higher level of SC (*M*) than control participants while performing the cognitive tasks, which did not interact with type of exposure. This finding is consistent with previous literature [e.g., Lyskov et al., 2001b; Regel et al., 2006; Rubin et al., 2006]. Lyskov et al. [2001a] have theorized that IEI-EMF individuals may suffer from a general imbalance in autonomic nervous system regulation. Future research is needed to clarify what causes higher levels of SC in sensitive individuals and what impact, if any, this has on their cognitive functioning. It is important to note that none of the other physiological measures differed between the two groups nor were they affected by type of exposure for any of the cognitive tasks.

IEI-EMF individuals consistently report memory and attentional difficulties that they believe are due to emf exposure from mobile phone base stations. Overall, cognitive functioning was not affected by short-term exposure to either GSM or UMTS signals in the current study. These findings are consistent with those of Haarala et al. [2003, 2005]; Regel et al. [2006]; Russo

et al. [2006]; Cinel et al. [2008]; Riddervold et al. [2008] and Unterlechner et al. [2008]. The current study did not examine the potential impact of longer-term exposure to emf on cognitive functioning.

To conclude, when Bonferroni corrections are applied to the data to control for familywise alpha error, the present study found no effects of either GSM or UMTS base station signals on cognitive functioning in either sensitive or control groups. Some may argue that given the widespread roll-out of mobile phone technology, it is important to be able to detect even a small effect in particular populations and thus the use of the Bonferroni correction is too strict. If Bonferroni corrections for multiple comparisons were not applied to the data, then the data suggest that the sensitive group had impaired performance on the DS task when exposed to both the GSM ($P = 0.019$) and UMTS ($P = 0.030$) signals compared to sham (Bonferroni correction $\alpha < 0.017$). However, the use of Bonferroni corrections is essential in controlling for the number of false positive results when multiple tests are conducted. In addition, the replication of findings is important in determining if positive results are due to real differences or due to chance. For example, Kwon et al. [2008]

reported that two participants in their study initially had accuracy rates of 94% and 97% in detecting the presence of emf produced by a GSM mobile phone. Upon retest 6 months later, the accuracy dropped to around 50% for both participants. So, even though it was extremely unlikely for either participant to have such high initial accuracy rates by chance, it did occur. It was only through replication that Kwon and colleagues were able to determine that the participants' initial accuracy did not reflect a true ability in detecting emf, but were false positive results. As researchers, it is important to remember that unlikely events can occur and when we conduct multiple tests we increase the likelihood of obtaining false positive results. Thus, we need to apply the appropriate tools of Bonferroni correction and replication of findings to control for false positive results and the incorrect conclusions resulting from these.

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