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Effect of 902 MHz Mobile Phone Transmission on Cognitive Function in Children

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We examine whether a standard mobile exposure at 902 MHz has a significant effect on cognitive function in 18 children 10–12 years of age. These were in a single group in which each child was given a single training session and then three test sessions in a randomized, three-way crossover design, using the cognitive drug research (CDR) cognitive assessment system. Exposures were 0, 0.025, or 0.25 W from a standard Nokia 3110 mobile phone handset mounted on a plastic headset in normal use position. The results of testing showed that the baseline (0 W) performance for the reaction time measurements was considerably slower than for the comparable measures in adult. There was a tendency for reaction time to be shorter during exposure to radiation than in the sham (baseline) condition, an effect that was most marked for simple reaction time. However, no effects reached statistical significance after Bonferroni correction. Therefore, we conclude that this study on 18 children did not replicate our earlier finding in adults that exposure to microwave radiation was associated with a reduction in reaction time. It should be noted that the present study investigated the effects of radiation from a GSM handset, whereas in our previous study the effect on reaction time was observed only with a more powerful analogue handset. Bioelectromagnetics Supplement 7:S138–S143, 2005. © 2005 Wiley-Liss, Inc.

Key words: GSM; reaction times; memory; children

INTRODUCTION

There are a number of studies reporting neurological effects of mobile phone-emitted electromagnetic fields (EMFs) [Preece et al., 1999; Koivisto et al., 2000a,b; Lee et al., 2001; Edelstyn and Oldershaw, 2002] that all reported at least one parameter change to give a facilitatory effect, that is, an enhancement of response in a range of computer-based tests. The results indicated a reduction of reaction time, whether simple or where there is an increase in cognitive load, such as choice reaction or N-back reaction. One of these groups has attempted to replicate the earlier findings with a double blind two-center study and reported no response to a standard mobile phone [Haarala et al., 2003] in terms of reaction time alteration and N-back reaction. In addition, one study at base station exposure level (1 V/m whole body) also showed similar cognitive changes in response to UMTS 3G transmission at 2100 MHz [Zwamborn et al., 2003].

However, other effects have been reported on brain function [Eulitz et al., 1998; Freude et al., 1998; Hamblin and Wood, 2002] and on sleep [Huber et al., 2002]. There is a suggestion that the effects are specific absorption rate (SAR) dependent. In our first study a response was obtained to an analogue (1 W) simulation but not to a simulated GSM transmission of 0.125 W, and the follow-up studies used a 0.25 W mobile phone in most cases. In view of the reported occurrences, the Stewart Report [IEGMP, 2000] recommended further research and, as a precautionary note, that children should be a special case because their physical size could affect SAR [Gandhi and Kang, 2002], because development is incomplete, and because children have a potentially longer lifetime exposure. All of these issues

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suggested increased susceptibility was a possibility. This has been disputed in the Health Council of the Netherlands Report to the Dutch Government [2002], which considered that the physical differences between adult and child skull and brain were not sufficiently large to affect the response to mobile phones. In addition, none of the foregoing studies on adults suggested any effects outside normal physiological ranges and certainly not health effects under the WHO definitions of health.

Research on children poses a special ethical consideration for non-therapeutic research, which has inhibited provision of a research study under the Mobile Telephones Health Research program in the UK. This study reports an adaptation of the earlier adult study that we have applied to children, taking into account the ethical constraints and using an equipment design to produce a realistic representation of mobile phone use with a test system acceptable to children.

MATERIALS AND METHODS

Subjects

A total of 18 children were enrolled into the study. All were members of the 1000 strong European Longitudinal Study of Parents and Children (born between January 1991 and June 1992) on the Isle of Man, UK. The reason for approaching this group is that these were well-characterized children who were used to participating in research, both directly and through the participation of their parents. The group consisted of nine boys and nine girls, living within a 10 mile radius of the study center, whose parents were happy for them to take part and who were able to attend and give consent. The response rate to the invitation to take part was 100% and all children satisfactorily completed the testing program. At the time of testing they were aged 10.2–12.2 years.

Ethical Approval

A Local Research Ethics Committee reviewed the full protocol with co-opted advice from paediatric consultants. The requirements were full consent by both parent/guardian and child, willingness to experience 30 min phone exposure under maximum power conditions and that only a standard GSM phone would be used. Children were eligible for selection only if they had previous and ready access to a mobile phone. The parents were able to sit and observe the training session only and were not present in the room during actual tests. Neither child, tester, nor parent was able to know which session used an exposure.

Exposure System

The phone used was a Nokia 3110 with WinTesla software to set up the exposure conditions. The only modification was the removal of the audio transducer to remove the induced low-level buzzing during high-power operation. The phone was situated in an acrylic cradle mounted on a plastic ear defender, replacing the earmuff on the left side. Three conditions were chosen, namely power off (this was true zero power and not standby mode when the phone could periodically attempt to contact a base station), power set at 0.2 W peak (0.025 W mean) and power set at 2 W peak (0.25 W mean). Once set, the phone was disconnected from the computer and handed to the tester. The same person tested all the children in order to minimize variation in tester influence. Setting was done according to a computer generated random table by a person independent of the testing. The phone was handed over after checking against a RF signal strength meter to ensure it was functioning as expected. Two phones were used so that a freshly charged unit was available for each test, whether powered or not.

The phones, supplied by Dr. Sakari Lang, Nokia, Finland, were compared for SAR on a homogeneous, anatomically realistic head phantom with a range of commonly available phones. Although not quite the highest, the SAR was near the top of the range for absorption of radio frequency radiation into the brain. This was approximately 0.28 W/kg, compared with 0.44 W/kg, the highest SAR generating GSM phone encountered during a series of measurements of a range of commonly available GSM phones on the CEPHOS complex head phantom (http://www.ebanet.it/Cephos.htm), and 0.02 W/kg, the lowest powered GSM phone studied. This can be compared with 1.2 W/kg for a 1 W analogue dummy phone used in our previous study [Preece et al., 1999]. Note that these measurements are for maximum brain SAR and not the maximum tissue SAR on which the standards are based. Interaction was measured as the E field in an anatomical, uniform phantom, 10 mm into the homogeneous tissue equivalent material of $\varepsilon = 40$, $\sigma = 0.86$ S/m using a Schottky diode mounted on a 6 mm dipole antenna and calibrated in brain equivalent fluid [CENELEC, 2000]. The values quoted here cannot be compared directly with standardized testing methods used in industry but give a relative measure of exposure to compare with our earlier study and with commonly available phone models.

Procedure

The number of subjects (18) allowed a fully balanced order of administration for three different

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conditions and was based on the sample size previously reported in adults. The number of subjects was further controlled by the Ethics Review Committee, whose remit is to minimize the number of subjects exposed to experimental procedure. A randomized crossover design compared three conditions, preselected by computer and designated X, Y, Z. With a few exceptions, each test was conducted at approximately the same time of day for each child on sequential days, 24 or 48 h after a practice test with no exposure. This experiment was conducted with a naïve group with one tester only, working to a strict script and timetable. The whole experiment was conducted within a school vacation to enable appointment times to be strictly observed.

Consistent testing conditions were maintained throughout the experiment. Children sat in a quiet room with good uniform lighting and only the tester present. Parents were able to witness the practice tests but not permitted to remain in the room for experimental sessions.

Performance Measures

The previously used tests from cognitive drug research (CDR) were used in a slightly modified form to suit children. These had been extensively validated for adults to demonstrate impairment or enhancement of mental efficiency in response to therapeutic agents [Bailie et al., 1989; Wesnes et al., 1989, 1997; Hanks et al., 1995]. They form a parallel series of tests with the advantage that progress through the tests was automatic controlled by the subject and needed no intervention by the tester except for a verbal explanation of each test. For the children, the only response needed was through a module with ''Yes'' and ''No'' buttons. The tests used, in order, are described in Table 1.

The tests provided three measures of performance:

(a) Reaction time (ms).
(b) Accuracy (% correct).
(c) A sensitivity index, which is a measure of the effect of presenting distractor (novel) information. This combines the accuracy score of the original response with that of the distractor response.

The series took about 30–35 min to complete.

Statistical Analysis

The effects of exposure on each of the measures were examined with one-way analyses of variance (three levels of the factor ''Exposure''). In each case the Huynh–Feldt correction was applied for sphericity. Since 22 such analyses were performed, probability was corrected for multiple comparisons with the Bonferroni method. The criterion for statistical significance was therefore $\alpha = 0.0023$. Since speed and accuracy may be correlated, Bonferroni correction for the total number of tests performed may be a particularly conservative criterion.

TABLE 1. Cognitive Drug Research (CDR) Computerized Cognitive Tests in Order of Presentation

Word presentation	A series of simple words are presented for a few seconds
Immediate word recognition	To test short-term memory a series of words that may or may not have been in the first presentation required a ''Yes'' for a match and ''No'' for a word not in the series
Picture presentation	A series of different pictures are presented for a few seconds each
Simple reaction time	The subject is required to press the ''Yes'' button when ''Yes'' appears on the screen
Digit vigilance	The subject must press ''Yes'' when the rapidly changing number in the center of the screen matches the one on the right
Word presentation	A series of simple words are presented for a few seconds
Immediate word recognition	A series of words that may or may not have been in the first presentation required a ''Yes'' for a match and ''No'' for a word not in the series to test short-term memory
Picture presentation	A series of different pictures are presented for a few seconds each
Simple reaction time	The subject is required to press the ''Yes'' button when ''Yes'' appears on the screen
Digit vigilance	The subject must press ''Yes'' when the rapidly changing number in the center of the screen matches the one on the right
Choice reaction time	The subject must respond with the ''Yes'' or ''No'' buttons to ''Yes'' or ''No'' presented on the screen
Spatial working memory	The subject is shown a picture of a house with nine windows, some of which are lit, followed by pictures of house with one window lit. The subject responds with ''Yes'' or ''No'' according to whether these match original picture
Numeric working memory	Five numbers are presented, followed by a sequence of single numbers, requiring a ''Yes'' response if a number was in the original sequence, or ''No'' if not
Delayed word recognition	A repeat of the first task to test the longer-term memory
Picture recognition	A series of pictures are presented which may or may not have been in the earlier showing and requiring a response of ''Yes'' or ''No''
Dual attention task	This is a repeat of the number vigilance task, requiring a ''Yes'' response when digits matched, but in addition a ''beep'' sometimes intervened and required a ''No'' (left-hand button) response

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As a further test for the effect of exposure on the three types of performance measure, two-way Analyses of Variance were performed on Reaction Time- × Exposure, Accuracy × Exposure, and Sensitivity × Exposure. The Huynh–Feldt correction was again applied for sphericity and the criterion for significance after Bonferroni correction taken as $\alpha = 0.017$.

RESULTS

Table 2 shows the 22 measures of reaction time, accuracy, and sensitivity provided by the test series (means over subjects), together with the single test F ratios and their probabilities before Bonferroni correction.

There are some trends in the direction of our earlier study in adults in which exposure to radiation was associated with a reduction in reaction time. Reaction time is longest in the sham condition in 7 of the 10 measures. The effect comes closest to reaching statistical significance in the case of simple reaction time ($P = .02$ (uncorrected)), but this did not reach the threshold for statistical significance after Bonferroni correction. Given the trend toward the longest reaction time in the sham condition, the effect of radiation on all ten measures of reaction time was examined in a two-way Analysis of Variance. The effect is not statistically significant (Exposure: $F = 1.49$; $df = 2, 34$; ns; Exposure × Tasks Interaction: $F = 1.05$; $df = 5.09, 86.4$; ns).

Individual tests of sensitivity and accuracy did not reach statistical significance. Nevertheless, there appeared to be some trends in the same direction as for reaction time. Accuracy was lowest in the sham condition in five of the seven tests of accuracy, and sensitivity was highest in the presence of the stronger EMF in four of the five measures of sensitivity. However two-way Analyses of Variance did not reveal that these effects were significant (Sensitivity measures: Exposure: $F = 1.98$; $df = 2, 34$; ns; Exposure × Sensitivity: $F = 0.61$, $df = 5.01$, 85.2; ns Accuracy measures: Exposure $F = 2, 31$; $df = 2, 34$, ns Exposure × Accuracy $F = 0.97$; $df = 8.93, 151.8$; ns).

DISCUSSION

This study found trends toward faster reaction times, higher accuracy, and higher sensitivity in the presence of radiation from a GSM phone than in a sham condition. However none of these effects reached statistical significance. Although, the tests employed were very similar to those used in our previous study in adults [Preece et al., 1999] the effects seen in that study were not replicated. In the latter, a significant effect of exposure was found on choice reaction time. In the present study, the effect that came closest to statistical significance was simple reaction time.

The equipment and exposure system used in this study differ from that of our first study on mobile phone

TABLE 2. Analysis of Results

	Power condition				
Test	Full power	Low power	Sham	F ratio	*P*-value
Immediate word recognition sensitivity index	0.90	0.88	0.88	0.37	.70
Immediate word recognition reaction time	704.00	688.73	721.14	2.00	.15
immediate word recognition accuracy	93.06	90.28	89.82	0.79	.46
Simple reaction time	291.39	303.54	308.80	4.28	.02
Digit vigilance accuracy	90.74	91.23	89.51	0.46	.63
Digit vigilance speed	478.75	474.38	481.41	0.64	.53
Choice reaction time-accuracy	95.89	95.44	94.78	0.66	.52
Choice reaction time speed	480.33	490.04	485.08	0.28	.73
Spatial working memory- sensitivity index	0.85	0.88	0.81	0.79	.44
Spatial working memory-reaction time	806.22	715.94	791.51	1.56	.22
Numeric working memory sensitivity index	0.89	0.85	0.84	1.57	.22
Numeric working memory reaction time	765.33	767.52	773.12	0.04	.96
Numeric working memory original stimuli accuracy	92.59	87.78	87.04	2.54	.09
Delayed word recognition sensitivity index	0.79	0.77	0.73	2.22	.12
Delayed word recognition reaction time	721.27	734.49	754.48	1.15	.32
Delayed word recognition original stimuli—accuracy	77.32	74.54	70.83	1.32	.28
Picture recognition sensitivity index	0.79	0.74	0.76	0.59	.56
Picture recognition reaction time	872.76	857.56	877.76	0.32	.72
Dual attention digits recognized	93.70	95.43	94.57	1.02	.37
Dual attention—beeps detected	90.74	92.59	91.20	0.42	.66
Dual attention digits speed	495.91	486.76	490.94	0.48	.62
Dual attention beeps—speed	498.99	486.35	507.30	1.63	.21

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exposure in adults, although they were the same as that of Koivisto et al. [2000a,b] and Haarala et al. [2003]. Indeed in those and the present study the phones used were standard models. In Preece et al. [1999] it was only at the higher exposure, estimated from the recent measurements to be a peak cortical value of 1.2 W/kg, that an effect was observed. The lower power of the 0.125 W GSM simulation would have been only 0.15 W/kg under the same conditions, and indeed no significant effect to this lower GSM type exposure was shown with the number of subjects studied. The phones used here were the standard 0.25 W mean output with a SAR measured on our adult phantom, of approximately 0.28 W/kg. Measurement on a smaller (11 years old) child phantom did not give a different value.

A considerably greater variable is the brain exposure, and this could be the critical factor in whether a response is detected. The way the exposure system is mounted on the head considerably influences the absorption rate. A change of a few millimeters has a large effect, and certainly in the children it was difficult to get the phone in a comfortable position and maintain the antenna close to the head. The solution to this might be to have a specifically designed jig to set a constant distance from the skin and maintain an accurate anatomical position. This was not seen to be practical with a genuine phone and the hope of maintaining cooperation of the children. The possibility of using a more remote antenna or applicator to reduce the critical effect of distance would illuminate a larger volume of head; and in our case, the Ethics Review Committee did not consider a simulated exposure setup acceptable.

No evidence of an increased susceptibility to mobile phone effects was seen in the group of children studied here. This agrees with the negative replication study of Haarala et al. [2003]. It was assumed in that study that the loss of a response compared with the first study from Finland by Koivisto et al. [2000a] was a result of the better ''double blind'' status, the single condition of which could have led to the experimenter influencing the result.

The present findings are similar to those of a contemporaneous study by Haarala et al. [2005] with 36 children aged 10–14 years and an almost identical exposure system. They used only two exposure conditions, equivalent to the sham and 0.25 W conditions used here, and different cognitive tests, but tests which sought to measure similar reaction and memory parameters. That study also found no significant change with exposure and very similar reaction times to those found here. It is possible that a larger study might demonstrate small changes, but based on the variance found in this study, in order to demonstrate a similar change to that found in adults, namely −15 ms, at least 72 subjects would have been needed.

A remarkable finding was that in these tests, some of which were identical to the adult study, children were considerably slower than adults for both simple and choice reaction times, in word recognition and picture recognition times. Unfortunately, no other normal data are available for the specific set of tests used here because before this study they have only been applied to adults. The reason for the difference from the earlier study [Preece et al., 1999] is not clear because children appeared in this and the pilot study to be able to grasp the concept very quickly and indeed to enjoy the tasks and to be motivated to try their best. It is possible that they were very concerned to ''get it right'' and therefore hesitated. There is some evidence that psychomotor performance is not fully developed in 10–12 years old children [Wolff et al., 1998; Garvey et al., 2003] based on finger tapping speed. In that study 6–8 year old children had a mean tap time of 920 ms, 10–12 year old children a mean time of 720 ms, and adults, 460 ms. It is apparent, therefore, that our group is possibly in a state of rapid developmental change.

The use of a repeated measures design should have coped with this additional source of variation, but it does mean that the group is developmentally heterogeneous and the inter-subject standard deviation is likely to be greater than for a population of adults. Also, this group was a subset of the population at large, whilst our previous studies have used medical students or hospital staff who will have a narrow intelligence range. An advantage of the repeated measures design used in this study was that it should have allowed for this additional source of variation. It could not however allow for the effects of such a developmentally heterogeneous sample where the inter-subject standard deviation is likely to be greater than for a population of adults. Nor it could allow for the wider range of intelligence likely from a geographical population sample, compared with our previous studies of medical students and hospital staff.

On the other hand, the lack of any demonstrable effects of test order in this study and no consistent improvement in results with subject practice, except in two of the memory tasks, was similar to the findings of the adult study [Preece et al., 1999] and adds to, rather than undermines confidence in the validity of these measurements.

CONCLUSIONS

No significant effect of mobile phone exposure from a 902 MHz GSM phone was demonstrated with a range of cognitive tests at normal maximum operating

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power. It is apparent that children of even a narrow age range are cognitively a heterogeneous group, and therefore testing might require a much bigger sample to be studied if the change in performance were to be of the same order of magnitude as that seen in adults. It probably would not be ethically acceptable to carry out provocation studies at the higher powers of the now obsolete analogue phones employed in our previous study, which did demonstrate an effect of radiation. In view of the study by Haarala et al. [2004], which also found no effect even with a larger number of subjects, and the study reported here, there is no evidence that children present a more sensitive group than adults, either developmentally or physically by virtue of size, as was considered to be a possibility in the Stewart report [IEGMP, 2000].

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