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*Brief Communication*

# Cognitive Effects of Cellular Phones: A Possible Role of Non-Radiofrequency Radiation Factors

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Some studies found that cognitive functions of human beings may be altered while exposed to radiofrequency radiation (RFR) emitted by cellular phones. In two recent studies, we have found that experiment duration and exposure side (i.e., phone's location—right or left) may have a major influence on the detection of such effects. In this brief follow-up experiment, 29 right-handed male subjects were divided into two groups. Each subject had two standard cellular phones attached to both sides of his head. The subjects performed a spatial working memory task that required either a left-hand or a right-hand response under one of the two exposure conditions: left side of the head or right side. Contrary to our previous studies, in this work external antennas located far away from the subjects were connected to the cellular phones. This setup prevents any emission of RFR from the internal antenna, thus drastically reducing RFR exposure. Despite that, the results remain similar to those obtained in our previous work. These results indicate that some of the effects previously attributed to RFR can be the result of some confounders. Bioelectromagnetics 32:585–588, 2011. © 2011 Wiley-Liss, Inc.

**Key words: radiofrequency radiation; cognitive effects; cellular phones**

Some studies, recently reviewed by Barth et al. [2008], found that cognitive functions of human beings may be altered while exposed to radiofrequency radiation (RFR) emitted by cellular phones. In two recent studies, we have found that experiment duration, exposure side (i.e., phone's location—right or left) and responding hand may have a major influence on the detection of such cognitive RFR effects [Eliyahu et al., 2006; Luria et al., 2009]. We proposed that these parameters might explain the failure of certain studies to observe or replicate these effects. In addition, we argued that the involvement of some confounding factors must be considered, too. Some studies demonstrated that cellular phones expose the user, besides RFR, to low-frequency magnetic fields originating from the battery electric currents [Jokela et al., 2004; Ilvonen et al., 2005; Perentos et al., 2008] and to non-RFR heating [Straume et al., 2005; Anderson and Rowley, 2007]. However, to the best of our knowledge it was not examined yet whether the reported cognitive effects were mediated by RFR or by these confounding factors. We herein report the results of a brief experiment designed to determine whether our findings can be attributed to RFR or to other agents.

The experimental system was identical to the one described in our previous works, that is, each subject had two standard Nokia 5110 Global System for Mobile Communications (GSM) cellular phones (Nokia, Helsinki, Finland) attached to both sides of his head by a specially designed non-conductive frame. The cellular phones' transmitted power was controlled by an HP GSM test system (Model E6392B, Hewlett Packard, Palo Alto, CA). This system maintained the phones at either no transmission or full power transmission (890.2 MHz, 2 W peak power). The maximum specific absorption rate

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(SAR) value reported for the Nokia 5110 model ranges from 0.54 to 1.09 W/kg, depending on the phone position [DASY Test Report, 2000]. The phones were located in a position as similar as possible to that of typical use, and the antenna was located approximately 1.5 cm away from the subject's head. The communication between the phones and the test system was wireless, at an extremely low output power (0.01 mW), and thus considered negligible. The phones were battery operated during the experiment. They were attached to the subject's head before the first task and dismounted at the end of the experiment. The experiment was approved by the Ethical Helsinki Committee of the Soroka Medical School at Ben-Gurion University (Beer-Sheva, Israel). Prior to the experiment, the subjects completed a questionnaire concerning intakes of tea, coffee, alcohol, and the amount of sleep they had. All participants reported adequate sleep the night prior to the experiment, and they had not drunk excessively (thus, all subjects were included in the analysis). The RF exposure regime was single-blinded, that is, the experiment manager was aware of the exposure mode while the subjects were not (the phones were silent during the whole test). An opaque partition was placed between the experiment manager and the subjects during the experiment. The experiment manager controlling the cellular phones was not the one giving the instructions to the subjects; though, both the experiment manager and the person giving instructions were aware of the exposure condition.

The main innovation of this study is the following: external remote antennas were connected to the cellular phones preventing any emission of RFR from the cellular internal antenna. The external antennas were placed approximately 2 m away from the subjects, thus drastically reducing RFR exposure ($<0.1\ \mu W/cm^2$ were measured at the subject's location), but exposure to non-RFR factors such as non-RFR heating and low-frequency magnetic fields remained unchanged.

A total of 29 healthy right-handed male subjects were randomly divided into two groups. The subjects in each group were exposed to only one of the two exposure conditions: left side of the head (15 subjects) or right side (14 subjects). Sham exposure was deemed unnecessary for this study. The subjects performed the same spatial working memory task as in our previous study—"Face" [Luria et al., 2009]. The task proceeds as follows: three target "faces" are presented (for 650 ms each) in three random locations (out of eight possible). These eight possible locations are positioned as a $3 \times 3$ square (excluding the middle position). After an additional 3000 ms, another face appears in a random position. The subject has to decide whether the last face location matched any of the preceding three locations, and to respond by pressing a key with either the right hand (to mark a match) or the left hand (a mismatch), using the "/" key and the "z" key, respectively. Since the previous study revealed differences in response times (RTs) only during the first time segments, we concluded that three time segments, 50 trials each, will be adequate for the current study. At the end of each experiment, subjects were asked whether they could detect if and which phone was operating; all reported that they could not.

Trimming criteria (used to get rid of outliers and increase the statistical power) and Greenhouse–Geisser corrections (used to address potential violations of the ANOVA assumptions) were the same as in our previous work. No trend for speed accuracy was found. An ANOVA on RT with exposure group (right-side exposure vs. left-side exposure), segment (1–3), and responding hand (left vs. right) as independent variables yielded a main effect of hand ($F(1,27) = 6.70$, $P < 0.05$), indicating that right-hand responses were 54 ms faster than left-hand responses, and an interaction between segment and hand ($F(2,54) = 3.69$, $P < 0.05$), indicating that segment affected mostly right-hand responses (by 40 ms, and only 4 ms for left-hand responses). Importantly, the triple interaction between group, responding hand, and segment was also significant ($F(2, 54) = 6.6$, $P < 0.05$). We employed one-sided *t*-tests to explore the source of this interaction, which is justified by the fact that this is a follow-up experiment.

As can be seen in Figure 1, during the first block, the average RT of the right-hand responses under left-side exposure showed a trend for longer RT (by 104 ms) relative to the right-side exposure ($t(57) = 1.52$, $P = 0.06$), as indicated by a *t*-test. These results are similar to those obtained in our last work (in which, apart from the RFR exposure, we employed an identical procedure), where the difference between the exposure conditions (right side combined with sham exposure vs. left exposure) was 146 ms. In order to confirm that the 104 ms difference in this experiment is not statistically different from the 146 ms difference found in the previous work, we conducted another analysis comparing the current results to the first three blocks from our previous work (with experiment as a between-group variable).

This analysis showed that none of the effects involving experiment even approached significance

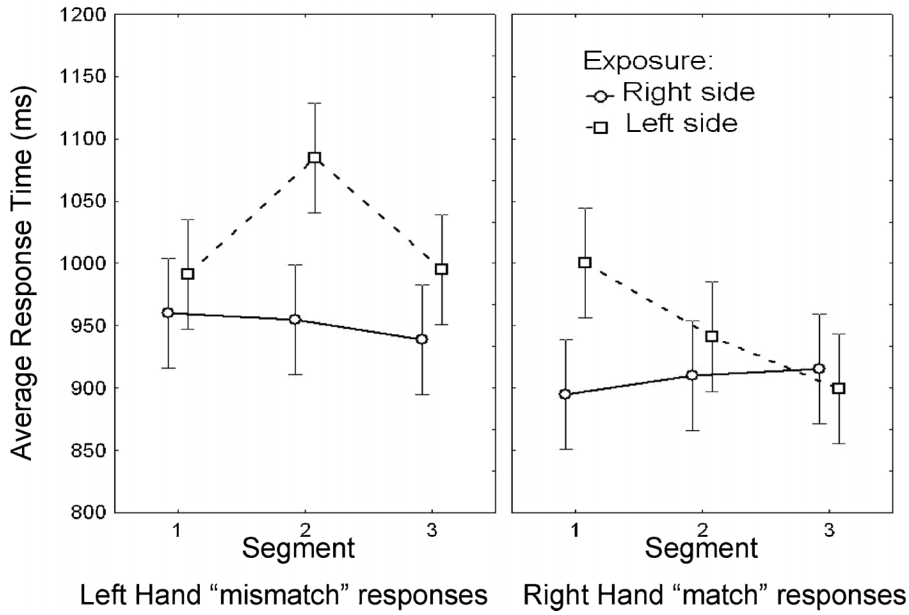


Fig. 1. Response times in ms for the right-hand (match) responses (right panel) and the left-hand (mismatch) responses (left panel) for the two exposure conditions. Error bars represent the standard error of the mean.

($F(1,59) < 1$, $P > 0.9$), indicating that the variance due to the effect did not exceed the error variance. Thus, we can conclude that the results of the present experiment are statistically indistinguishable from those of the previous experiment. It should be noted that this time, left-hand responses showed a different pattern from right-hand responses and from our previous work.

To summarize, the present study shows that the changes in RTs that were reported in our previous work, and were assumed to be mediated by RFR exposure, remain similar when the radiating antennas are placed far away from the subjects, thus drastically reducing RFR exposure (i.e., in both our studies, average RT of the right-hand responses during the first block was longer under left-side exposure than under other exposure conditions).

It should be noted that our design involved two separate groups, each exposed to one side of the head only (i.e., a between-subjects design). This design added noise to our analysis, thus making it more difficult to observe significant effects. Especially with small groups, the observed effects might reflect differences between the groups rather than sensitivity to the manipulation. However, the advantage of the between-subjects design is the prevention of practice and fatigue influence from one exposure group to the other. This is particularly important since our previous study demonstrated that the observed effect was confined to first time segments only. Another limitation of the current study is that a double-blind procedure was not employed.

These results indicate that some of the effects previously attributed to RFR can be the result of some confounders. Non-RFR heating caused by the phone and low-frequency magnetic fields originating from electric currents are possible explanations (obviously, this assumption is not applicable to the few studies that did not use a phone for generating the exposure but only an antenna, e.g., Preece et al. [1999] and Regel et al. [2007a, b]). It is important to note that this criticism might be valid for other experiments that use cellular phones as the source of RFR as well. Only by ruling out non-RFR agents as a source of an effect can one argue that RFR can indeed influence the central nervous system or cause any other effect.

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