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Effects of mobile phone signals over BOLD response while performing a cognitive task ☆

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HIGHLIGHTS

- Mobile phones effects had never been studied before with fMRI.
- Reaction times to a Go–NoGo task and the BOLD response were not affected by mobile phone exposure.
- Lack of effects of EMFs on brain functioning could rely on both method limitations and sample size.

ABSTRACT

Objective: The aim of this study was to investigate the effects induced by an exposure to a GSM signal (Global System for Mobile Communication) on brain BOLD (blood-oxygen-level dependent) response, as well as its time course while performing a Go–NoGo task.
Methods: Participants were tested twice, once in presence of a "real" exposure to GSM radiofrequency signal and once under a "sham" exposure (placebo condition). BOLD response of active brain areas and reaction times (RTs) while performing the task were measured both before and after the exposure.
Results: RTs to the somatosensory task did not change as a function of exposure (real vs sham) to GSM signal. BOLD results revealed significant activations in inferior parietal lobule, insula, precentral and post-central gyri associated with Go responses after both "real" and "sham" exposure, whereas no significant effects were observed in the ROI analysis.
Conclusions: The present fMRI study did not detect any brain activity changes by mobile phones. Also RTs in a somatosensory task resulted unaffected.
Significance: No changes in BOLD response have been observed as a consequence of RF-EMFs exposure.

1. Introduction

As a consequence of the exponential increase in mobile phone (MP) use, several studies investigated the acute effects of radiofrequency electromagnetic fields (RF-EMFs) on both behavioral-cognitive and neurophysiological indexes of brain function (Valentini et al., 2007; Kwon and Hamalainen, 2011; Valentini et al., 2010).

Most of them showed an influence of RF-EMFs on behavioral and cognitive measures generally reporting improvement of performance (Koivisto et al., 2000a,b; Curcio et al., 2004; Regel et al., 2007a), on waking EEG with a marked influence on alpha rhythm (Croft et al., 2002, 2008; Curcio et al., 2005), and on sleep EEG, in which RF-EMFs influenced the alpha-sigma range (Huber et al., 2002; Regel et al., 2007b). On the other hand, some studies reported no influence at all on brain function (Roschke and Mann, 1997; Hietanen et al., 2000; Wagner et al., 2000; Russo et al., 2006; Terao et al., 2006; Fritzer et al., 2007; Kleinlogel et al., 2008; Furubayashi et al., 2009; Okano et al., 2010), while some of those with positive results show several methodological limitations and statistical biases (Valentini et al., 2007; Kwon and Hamalainen, 2011; Valentini et al., 2010). Finally, early behavioral and cognitive investigations reporting an improved performance, could not be replicated (Curcio et al., 2008; Haarala et al., 2003a,b, 2004).

☆ The experimental sessions and measurements were carried out at I.T.A.B., Università G. D'Annunzio, Chieti, Italy.

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Heterogeneity in results may be due to striking differences in methodology, statistical power and interpretation criteria (Kwon and Hamalainen, 2011; Valentini et al., 2010).

With the aim to test the MP-induced effects on brain excitability, Transcranial Magnetic Stimulation (TMS) was employed in two different studies (Ferreri et al., 2006; Inomata-Terada et al., 2007). According to a cross-over, double-blind paradigm, participants were exposed for 45 min to a typical basic GSM signal. Cortical excitability was assessed before (baseline), immediately following "real" or "sham" exposure, and after a one-hour interval. Results showed that intracortical excitability significantly increased only after "real" exposure to the GSM signal, selectively for the exposed hemisphere, and for a limited period of time (baseline conditions almost completely regained 60 min after the end of exposure). This effect was explained by a concurrent reduction of intracortical inhibition and an enhancement of intracortical facilitation (Ferreri et al., 2006). The other study (Inomata-Terada et al., 2007) used a single-pulse TMS protocol, before and after 30 min MP exposure, stimulating three sites (motor cortex, brainstem and spinal nerve) and recording both motor evoked potentials (MEPs) and the short-interval intracortical inhibition (SICI). Neither MEPs nor the SICI resulted affected in normal individuals. This study also investigated for the first time MEPs after MP exposure in multiple sclerosis patients. Again, no effects on any parameters of MEPs were observed on neurological patients. Authors ascribed this lack of effects to small sample size.

Neuroimaging studies using Positron Emission Tomography (PET) showed a change of cerebral blood flow after exposure to the RF-EMFs. Huber et al. (2002) in a double blind procedure exposed their experimental subjects for 30 min, using two planar antennas emitting RF-EMFs only on the left side. They observed that only under "real" exposure rCBF (regional cerebral blood flow) significantly increased on the exposed dorsolateral prefrontal cortex. A subsequent paper by the same group (Huber et al., 2005), re-assessed the effect of RF emissions on cerebral metabolism by using the same experimental procedure and physical parameters as in their previous study with the only difference that a cellular phone-like and a "base-station-like" signal was employed. Enhanced regional metabolism on the exposed (left) dorsolateral prefrontal cortex, when the same RF signal was compared with a "base-station-like" signal was statistically significant.

On the other hand, two consecutive studies by the same research group (Haarala et al., 2003a; Aalto et al., 2006) did not show any rCBF modification as a function of the exposure to RF GSM-like signals during performance on a visual memory task.

Subsequently, Mizuno et al. (2009) investigated the effects of a third generation MP signal (CDMA technology). The authors carried out a single blind crossover randomized design in which the participants' rCBF was assessed before, during and after both a "real" and a "sham" unilateral EMF 30 min exposure. Results showed that rCBF did not significantly change during or after EMF exposure.

Finally, a recent paper (Volkow et al., 2011) instead of rCBF measured the brain glucose metabolism assessed by means of (^{18}F) fluorodeoxyglucose (^{18}FDG) – a more proximal marker of neuronal activity than CBF – that allows the assessment of the cumulative effects of MP exposure on resting metabolism. Participants from a large sample size ($N = 47$) were exposed for 50 min to both a "real" and "sham" condition. Metabolism in the region closest to the antenna resulted significantly increased (about 7%) only during 'real' exposure. Moreover, these increases were significantly correlated with the estimated EMF amplitudes in the same areas. Differently from previous studies, an increase of brain glucose metabolism in the region closest to the antenna, clearly indicating a link with the effective absorption of EMF signal was shown.

Taken together, these data indicate that exposing the brain to a MP may induce an overall increase in brain metabolism, even if substantial differences can arise from the different measure considered (rCBF or glucose metabolism).

Finally, two studies have been carried out for evaluating the blood oxygenation changes measured via functional Near-InfraRed-Spectroscopy (fNIRS) after exposure to GSM signal, showing again contradictory results. In the first study (Wolf et al., 2006), results showed that during exposure, a close-to-significance short-term decrease of oxy- (O_2Hb) and increase of deoxy-hemoglobin (HHb) concentration were present. In the last study (Curcio et al., 2009), participants underwent two sessions ("real" and "sham" exposure) following a crossover, randomized, double-blind paradigm, using a typical basic GSM signal. fNIRS showed a slight influence of GSM signal on frontal cortex, with a linear increase in (HHb) as a function of time limited to the "real" exposure condition.

On the whole, results on the possible effects of MP exposure on cognitive, neurophysiological and neuroimaging parameters seem to indicate a very complex and often contradictory scenario.

The present study aims to evaluate for the first time the possible effects induced by brain exposure to GSM emissions by a commercially available mobile phone (with known dosimetric characteristics) on measures of blood-oxygen-level dependent (BOLD) by means of fMRI and its time-course, as well as on reaction times and levels of efficiency in performing a cognitive task.

2. Methods

2.1. Participants

Twelve young and healthy male volunteers were enrolled (age range: 19–25, mean: 21.4, SD: 2.0). Female volunteers were not recruited in order to avoid the hormonal effect on brain flow/metabolism and excitability due to the menstrual cycle (Goldstein et al., 2005). None had a past history of head injury, mental illness, neurological diseases, substance abuse, or contraindications for MRI. All participants were right-handed as assessed by the Italian version of the Edinburgh Handedness Inventory (Salmaso and Longoni, 1985) with a L.Q. $\geqslant$ 0.67. Participants were instructed to abstain from alcohol and medications and to maintain their own regular sleep–wake schedule on the preceding 3 days. Caffeine was allowed on the basis of individual habits (maximum 2 cups a day). Compliance was assessed with a sleep/wake-log that participants were asked to fill in every day. Each participant held a personal mobile phone but no one was a heavy user: the sample used the phone 0.98 h per day (±0.59; range 0.25–2.0 h). MP use was not allowed during the 12 h preceding the experimental session.

All volunteers gave written informed consent prior to the experiment, and were paid for their participation. The study was approved by the local Ethical Committee and it was conducted according to the principles established in the Declaration of Helsinki.

2.2. Procedure

Participants performed a somatosensory *Go–NoGo* task, in which they had to distinguish *Go* (paired pulses, separated by an interval of 150 ms) from a *No-Go* (single pulses) electrical stimulations, reacting only to the former by pressing a button with the same hand receiving the stimulus. There were 50 *Go* stimuli (25 over the right and 25 over the left hand), and 50 *No-Go* stimuli (distributed the same way) in each experimental run (see below). Inter-stimulus intervals (ISIs) varied among 3670, 5505 or 7340 ms. Stimuli were administered by a MATLAB script synchronized with the scanner trigger, which randomized Go and No-Go stimuli over both hands, and collected participants' responses. The electrical stimulus was a rectangular pulse with 200 µs