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The effect of electromagnetic field emitted by a mobile phone on the inhibitory control of saccades

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ABSTRACT

Objective: To investigate whether exposure to a pulsed high-frequency electromagnetic field (pulsed EMF) emitted by a mobile phone has short-term effects on the inhibitory control of saccades.
Methods: A double-blind, counterbalanced crossover study design was employed. We assessed the performance of 10 normal subjects on antisaccade (AS) and cued saccade (CUED) tasks as well as two types of overlap saccade (OL1, OL2) task before and after 30 min of exposure to EMF emitted by a mobile phone or sham exposure.
Results: After EMF or sham exposure, we observed a slight but significant shortening of latency in the CUED and OL2 tasks. AS amplitude decreased as well as the saccade velocities in the AS, CUED, and OL1 tasks after exposure. These changes occurred regardless of whether exposure was real or sham. The frequencies of prosaccades in the AS task, saccades to cue in the CUED task, and prematurely initiated saccades in the overlap (OL2) task did not change significantly after real or sham EMF exposure.
Conclusions: Thirty minutes of mobile phone exposure has no significant short-term effect on the inhibitory control of saccades.
Significance: The cortical processing responsible for saccade inhibition is not affected by exposure to EMF emitted by a mobile phone.

1. Introduction

The widespread use of mobile phones has led to growing concerns about their effects on health, and above all, about the potential effects of the electromagnetic fields (EMF) they emit. Accordingly, there is more and more interest in studying the effects of the high-frequency electromagnetic fields (EMF) emitted by mobile phones on the human body, especially the human brain, using various methodologies (Reiser et al., 1995; Freude et al., 1998; Eulitz et al., 1998; Preece et al., 1999; Borbely et al., 1999; Koivisto et al., 2000a,b; Huber et al., 2000; Krause et al., 2004; Sandstrom et al., 2001; Croft et al., 2002; Arai et al., 2003; Lee et al., 2001; Haarala et al., 2004; Hamblin et al., 2004, 2006; Hinrichs and Heinze, 2004; Maier et al., 2004; Sienkiewicz et al., 2005; Terao et al., 2005, 2006, 2007; Yuasa et al., 2006; Furubayashi et al., 2009; Mizuno et al., 2009).

Though their findings are still controversial, some studies have concluded that mobile phone use may influence cognitive brain functions, especially attention, in humans (Freude et al., 1998; Preece et al., 2005; Lee et al., 2001; Huber et al., 2002; Edelstyn and Oldershaw, 2002; Russo et al., 2006). Visual spatial attention has recently been demonstrated through brain-imaging studies to be controlled by most of the same underlying cortical structures controlling eye movements (e.g., saccades) (e.g., Nobre et al., 1997, 2000; Büchel et al., 1998; Corbetta et al., 1998; Schall and Thompson, 1999; Mort et al., 2003). We have previously reported that 30 min of mobile phone use has no effect on subject performance on elementary and simple saccade paradigms, such as visually guided saccade, gap saccade and memory-guided saccade tasks (Terao et al., 2007), suggesting that the cortical processing structures responsible for saccades and attention are not affected by exposure to EMF emitted by mobile phones. In this study, we investigated the effects of EMF on oculomotor paradigms, requiring both initiation and inhibition of saccades depending on the behavioral context, which were considered to be more sensitive to the EMF. It was considered important to investigate such tasks, since the ability to initiate a voluntary

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action, to inhibit an unwanted one, and to postpone an action until the context is appropriate is one of the most important yet fundamental cognitive functions of the brain (Aron et al., 2007).

The aim of the present study was to investigate the effect of EMF emitted by a digital mobile phone on the inhibitory cortical functions of the brain using oculomotor paradigms. Because they require more complex cognitive processing than the elementary tasks employed in our previous study did (Terao et al., 2007), these oculomotor tasks involving inhibitory function were expected to exhibit more susceptibility to any effects of EMF. Oculomotor paradigms are especially useful for this purpose, because they are particularly easy to record and lend themselves to quantification, thereby allowing the precise analysis of control mechanisms (White et al., 1983). Huber et al. (2002, 2005) reported that 30 min of digital mobile phone use induced regional cerebral blood flow (rCBF) changes in the dorsolateral prefrontal cortex on the exposed side. Furthermore, the neural substrate for inhibition is known to include the ventrolateral frontal cortex (Aron and Poldrack, 2006; Aron et al., 2007; Chikazoe et al., 2007; Hodgson et al., 2007). Thus, since many people hold their mobile phones against their heads in a rather anterior position, cognitive tasks involving inhibitory motor control are especially relevant for considering the effects of EMF emitted by mobile phones on brain function. In view of the functions of the cortical regions where rCBF changes were observed, exposure of the brain to EMF emitted by a mobile phone could lead to impairment in working memory (dorsolateral prefrontal cortex) and/or in the inhibitory motor and oculomotor functions (ventrolateral prefrontal cortex).

In this study, we assessed subjects' performance on four tasks. The antisaccade task that we used has been extensively used elsewhere as a counterpart of the no-go task (Everling and Fischer, 1998). In addition, we used the cued saccade and overlap saccade tasks to investigate inhibitory control under different conditions.

2. Methods

2.1. Subjects

Ten normal subjects (3 men, 7 women, age 35.2 ± 7.5 years [mean ± standard deviation], range 24–47 years), all of whom were right-handed, participated in the present study. The subjects gave their written informed consent to the study, which was approved by the Ethics Committee of the University of Tokyo according to the Declaration of Helsinki. None of the participants reported any psychological or neurological disorders or serious head injury, and none of them had used hands-free devices immediately prior to or during the experiments. A summary of subject characteristics, including age, occupation, psychosocial workload, VDT work, amount of time spent using a mobile phone, calling time, and number of calls per day, is given in Table 1.

Table 1
Subject characteristics.

Age	
<30 years	3
30–39 years	4
40–49 years	3
>50 years	0
Occupation	
Management	1
Professional	9
Intermediate	0
Psychosocial workload	
Low	2
Medium	6
High	2
VDT work	
No VDT work	0
<1 h/day	0
1–4 h/day	2
>4 h/day	8
Time with MP	
2–7 years	0
8–14 years	10
15–22 years	0
Calling time (min/day)	
<2 min/day	4
2–15 min/day	6
>15 min/day	0
Number of calls/day	
<2 calls/day	3
3–8 calls/day	5
>8 calls/day	2

2.2. Experimental setup

The experimental setup with regard to the mobile phone was similar to that described in our previous papers (Terao et al., 2006, 2007). Briefly, pulsed EMF was delivered through a handset (SH905i, Sharp, Osaka, Japan) connected to a cellular phone simulator (MT8815B cellular phone communication tester, Anritsu, Kanagawa, Japan). This system was set to deliver 250 mW through the handset during exposure; this is the maximum EMF output delivered by ordinary Japanese mobile phones (1.95 GHz EMF at 0.27 W net antenna input power, 250 mW) according to the criteria given in ARIB STD-T63 (Association of Radio Industries and Businesses Standard T63). The pulse structures of this system were: transmitting frequency: 1.95 GHz band; modulation scheme: $\pi/4$ shifted quadrature phase-shift keying; multiple access: three channel time division multiple access; time division of multiple access frame period: 20 ms; time slot: 6.7 ms; maximum transmitting power: 270 mW as the averaged value (0.8 W of burst power). The audio circuitry of the handset was disabled so as not to provide the subjects with acoustic cues indicating the status of the phone. During the 30-min exposure period, the handset was held over the left ear by means of a holder that fixed the handset at a distance of 2 cm from the scalp.

2.3. Recording procedure

For the measurement of saccades, we recorded electrooculography (EOG) as described previously (Terao et al., 1998, 2007). A personal computer was used to control the visual stimulus presented during the task and to acquire data in real-time. The recording setup for target presentation was originally developed by Kato and Hikosaka (1992), Kato et al. (1995) and modified by Hikosaka et al. (1993) for human use. A microcomputer system built according to this prototype controlled the behavioral paradigms in an interactive manner and stored analog (e.g., eye movement) and digital data (e.g., the times at which the switch button was pressed and released) for later offline analysis.

The subjects were seated in front of a black, concave dome-shaped screen, 90 cm in diameter, with their heads placed on a chin rest to restrain head movement. They faced the center of the screen, set at a viewing distance of ~66 cm, where the pinhole used as the central fixation point was located. The subjects held a microswitch button connected to the microcomputer, allowing them to initiate and terminate each task trial by pressing and releasing the button.

Electrooculographic (EOG) recordings were made through two Ag–AgCl gel electrodes placed at the bilateral outer canthi to record horizontal eye movements, and the signals were fed to a