Assessment of 60 Hz MF exposure up to 7.6 mT on human brain activity: a simultaneous EEG/fMRI study

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Short abstract (500 characters max): 461 characters

OBJECTIVE: Measuring effects of 60 Hz MF exposure up to 7.6 mT on human brain activity.
METHODS: Integrated EEG/fMRI in 3, 5 and 7.6 mT MF conditions delivered by a 3T MRI scanner.
RESULTS: No significant changes on the EEG alpha power (8-12 Hz) or fMRI activation were found in any of the three conditions tested.
CONCLUSIONS: The threshold for acute, detectable changes in EEG or functional brain activation is higher than 7.6 mT at 60 Hz.

Long abstract (12,000 characters max): 11,151

Introduction

There is experimental evidence that human exposure to extremely low-frequency (ELF) magnetic fields (MF) can result in the modulation of brain electric (measured by electroencephalography, EEG) and functional (as measured by functional magnetic resonance, fMRI, measuring the blood oxygen level dependent –BOLD-signal) activity. For example, studies have pointed at the possible decrease in EEG alpha (8-12 Hz) activity due to specific ELF MF exposure [1,2]. In terms of effects on brain functional activity, it has been shown that a one-hour human exposure to a 3 mT MF at 60 Hz can result in a modulation of the brain activation associated with a finger tapping task or a mental rotation task [3]. Since EEG alpha activity is known

to be negatively correlated with the BOLD signal [4], this supports that a 3 mT MF at 60 Hz might decrease EEG alpha activity in humans.

Since most studies reporting effects of ELF MF on brain activity indicate that the human EEG is prone to modulations in the occipital lobe in the alpha band, we have focused our study on occipital cortex activity (O2, O1 and OZ EEG electrodes). Based on the literature, we hypothesize that 1) EEG alpha activity will decrease in O2, O1 and OZ electrodes during exposure compared to no exposure; 2) since EEG alpha activity and the BOLD signal are negatively correlated, brain functional activity will increase during MF exposure.

Material and methods

General. N=25 healthy volunteers (age 24.16±6.2) were enrolled in this experiment, with ethics approval (REB #17816) from the Health Sciences Research Ethics Board of Western University (London, ON). Exclusion criteria included the presence of any metallic object implanted in body, or cardiovascular/neurological disorders. Subjects were randomly assigned to one of two different subgroups (see Figure 1 for details) after interaction with participants was finished and that they were setup in the MRI scanner.

Figure 1. Illustration of the EEG/fMRI protocol for the two subgroups of subjects. Subgroup 1 included N=13 subjects, whereas Subgroup 2 was including N=12 subjects (N=25 overall).

MF exposure. MF exposure at 60 Hz was delivered using a Siemens 3T MRI/PET Biograph, on which only the MRI functionality was used. Three different levels of MF flux density were used (see Figure 1) with different durations: 3 mT (10 s), 5 mT (10 minutes) and 7.6 mT (2 s), which were chosen according to MRI technical

constraints detailed as follows. The MF flux density is zero at the MRI bore isocentre, and increases linearly up to 20 cms along the Z-axis and then decays. Therefore the maximum Z-gradient value used in this study was 38 mT/m at 20 cms from isocentre, corresponding to a MF flux density of 7.6 mT. Functional (fMRI) images quality was preserved up to 8 cms from the isocentre, resulting in a 60 Hz MF exposure at 3 mT at 38 mT/m (the exposure protocol did not involve any table movement to acquire functional images at the isocentre, preventing further induced currents during table movements). Finally, for an MF exposure of 10 minutes, maximum MF flux density was 5 mT at 25 mT/m to avoid MRI gradient amplifiers shutoff (built-in MRI software safety to prevent amplifiers heating and damage).

EEG. We used an MRI-compatible, 64-channel EEG cap and amplifier (Compumedics-Neuroscan, USA), synchronized with the MRI scanner clock. Electrodes were filled with a specific saline solution (QuikCell, Compumedics-Neuroscan, USA) to bring electrodes' impedance below 5 kΩ. The MRI cold head was turned "off" to improve signal/noise ratio during the entire experiment. EEG was acquired during each imaging and MF exposure sequence (see Figure 1). MRI-induced EEG artefacts (e.g., heartbeat artefacts, gradient field artefacts) were corrected, and resulting EEG bandpass-filtered (5-15 Hz) using the software Curry 7.0 (Compumedics-Neuroscan, USA), and then exported in text format for further analysis. EEG alpha power was then calculated for "exposure" and "sham" conditions in each of the three MF exposure sequences using custom-made scripts in Matlab (The Mathworks, USA).

fMRI. A full 3D anatomical image of subjects' brain was acquired. For the fMRI/EEG sequence (see Figure 1), a novel BOLD sequence was developed and designed specifically for this project to detect post-stimulus decreases in BOLD signal [5]. Anatomical and functional images were imported using BrainVoyager QX 2.8 (Brain Innovation, The Netherlands), and then correlated before being transformed in the standard Talairach space for group analysis. Results regarding Arterial Spin Labeling (ASL, see Figure 1) are not reported here and are still under analysis.

Statistical analysis. An ANOVA with multiple comparisons and within/between subjects factor was conducted to detect potential significant effects of the MF exposure on EEG alpha power, and the standard p-value of 0.05 was used. Group analysis of fMRI results was done using a General Linear Model analysis (GLM) available in BrainVoyager (Brain Innovation, The Netherlands), and the Bonferroni correction was applied to account for multiple comparisons.

Results

Results regarding the EEG alpha power for the occipital electrodes O2, O1 and OZ with/without exposure in all 60 Hz MF exposure conditions (3 mT, 10 seconds repeated 12 times; 5 mT, 10 minutes; 7.6 mT, 2 seconds repeated 100 times) are presented in Figure 2.

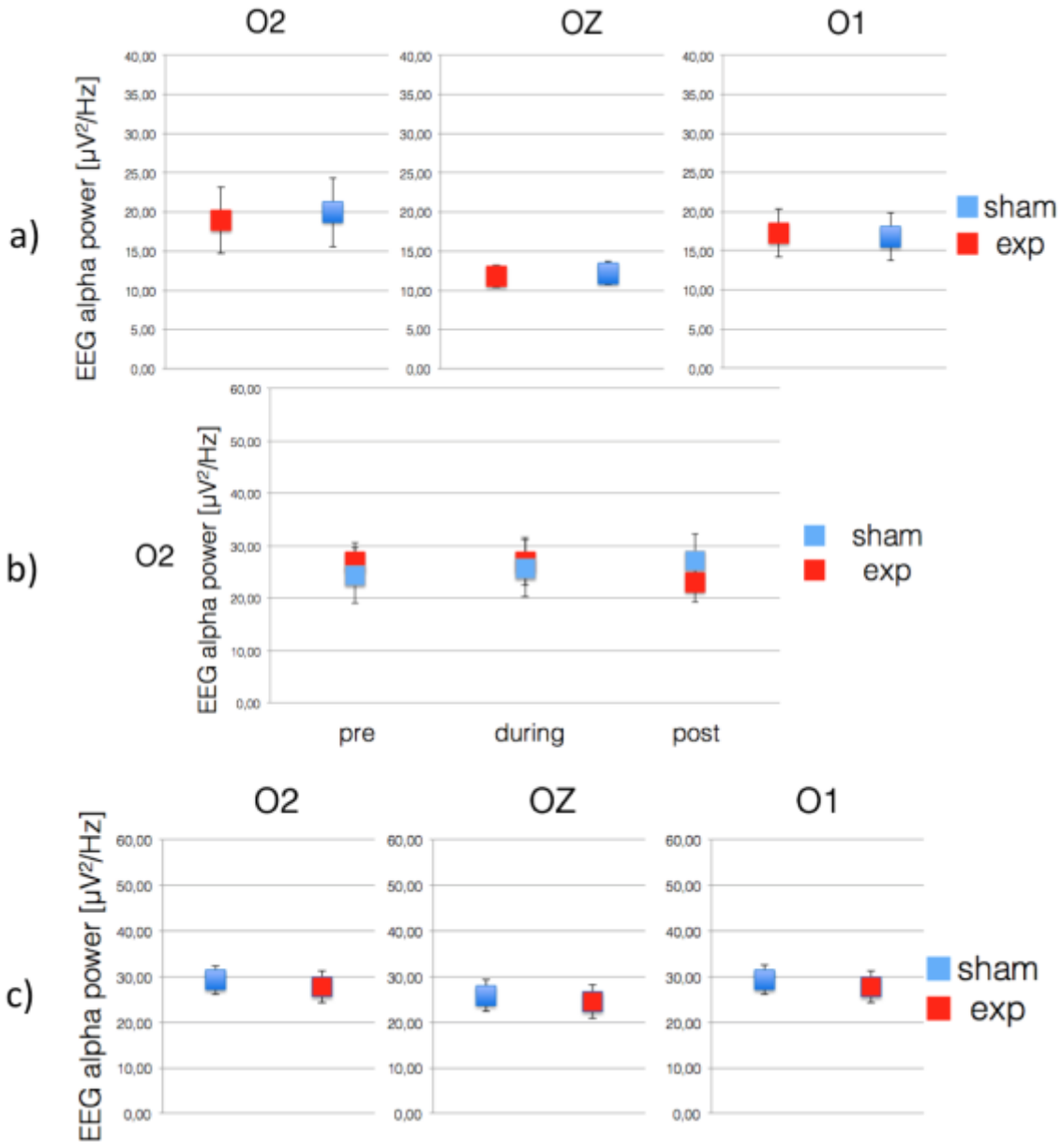

Figure 2. a) EEG alpha power in occipital electrodes without ("sham") and with ("exp") exposure to a 60 Hz MF at 3 mT (10 seconds blocks, repeated 12 times) delivered using the MRI Z-gradient coil (N=25). **b)** EEG alpha power pre-, during, and post-exposure in the occipital electrode O2 without ("sham") and with ("exposed") exposure to a 60 Hz MF at 5 mT (10 minutes) delivered using the MRI Z-gradient coil (N=25). **c)** EEG alpha power in occipital electrodes without ("sham") and with ("exposed") exposure to a 60 Hz MF at 7.6 mT (2 seconds blocks, repeated 100 times) delivered using the MRI Z-gradient coil (N=25). Error bars represent standard error of the mean (SEM).

Regarding the 3 mT MF exposure condition (Figure 2a), results from the ANOVA indicate that there was no significant difference between the EEG alpha power in the

"sham" and "exposed" conditions (p=.74, power=.1). In the 5 mT MF exposure condition, results presented in Figure 2b) show a trend for EEG alpha power to increase over time in the sham condition, while it decreases in the "exposed" condition. However, this result was not significant (p=.44, power=.2). Finally, regarding the 7.6 mT MF exposure condition, results shown in Figure 2c) suggest a decrease in EEG alpha power in the "exposed" condition, which was not found to be statistically significant (p=.084, power=.54) in any of the occipital electrodes (O2, O1, OZ).

Finally, we present in Figure 3 the GLM results regarding fMRI group results, immediately after the 10 seconds, 3 mT 60 Hz MF exposure (N=25).

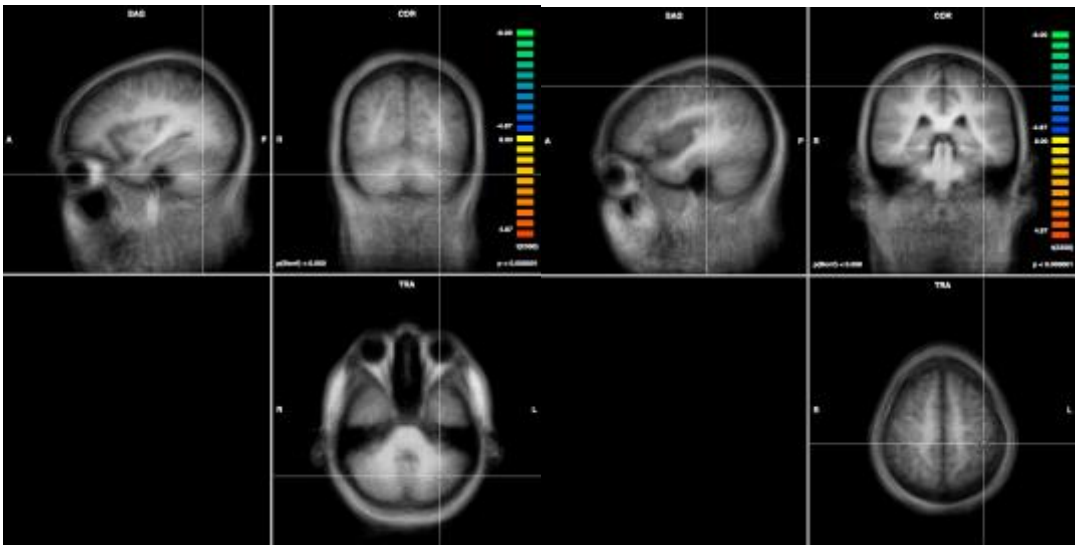

Figure 3. Example of GLM results in the left cerebellum (left figure) and in the motor cortex (right figure). No significant increase or decrease of functional activation is noticeable (the Bonferroni correction, taking into account multiple comparisons in the significance threshold, was used). Results are displayed over the averaged anatomical image for the 60 Hz group (N=25).

As can be seen in Figure 3, the GLM analysis did not identify any brain region with significantly modulated functional activation. We presented the motor cortex and cerebellum in Figure 3, since we had found in a previous experiment that 60 Hz MF exposure at the same MF flux density (3 mT) was able to induce, after one hour of exposure, an increase of brain functional activation in these regions [3]. The absence of effects after a shorter MF exposure duration is commented in Discussion.

Discussion and concluding remarks

In this study, we have performed integrated EEG/fMRI in healthy humans to investigate potential acute effects on brain electrical and functional activity of 60 Hz MF exposure up to 7.6 mT. Interestingly, no significant effects on EEG alpha power were found at any MF flux density investigated (3 mT, 5 mT, 7.6 mT) or duration (2 seconds, 10 seconds, 10 minutes). The absence of effects on the EEG is consistent with the lack of effect on brain functional activation as measured by BOLD immediately after 3 mT exposure. Therefore, this suggests that the 60 Hz MF exposure threshold for acute, detectable, systematic effects on electrical and functional human brain activity is higher than 7.6 mT. Let us note that this is not incompatible with previously reported effects of 60 Hz MF in the same flux density range, but using longer exposure duration. It might indeed mean that different mechanisms can be involved: acute effects, if they are observed, might result from direct neuron membrane polarization, while lasting effects might be the result of synaptic plasticity processes modulation [6,7].

Overall, we have pushed the technology of MRI used as an MF exposure system to the limits of what our available MRI scanner can provide (Siemens 3T MRI/PET Biograph). The MF flux density values used were indeed the highest that we could achieve given built-in gradient amplifiers safeties, size of the MRI gradient field linear zone, and fMRI image quality. Exploring higher MF flux density values, which would be needed to identify potential acute effects of 60 Hz MF exposure, would require to move away from MRI and using dedicated MF exposure systems capable of delivering higher flux densities. Our group has already initiated such effort and has been developing new exposure systems in this direction [8,9].

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