From Behavioral Monitoring to Functional Brain Imaging: Impact of a 60 Hz Magnetic Field at 1.8, 3 and up to 50 mT in Humans

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INTRODUCTION

Extremely Low Frequency (ELF, < 300 Hz) Magnetic Fields (MF) effects have been extensively studied over the last three decades (see [1] for an extensive review of the literature). However, the main limitation in this research field appears to be the difficulty to reproduce experimental results. One of the reported causes is the inconsistency in terms of MF characteristics used between experiments (differences in field duration, amplitude, frequency, intermittency, continuity etc.). Since 2005, we therefore decided to focus one of our research programs on 60 Hz MFs, with the strategy of gradually increasing the exposure levels until we could report a reliable effect in humans. The Phase I of this program was targeting the 1.8 mT MF amplitude, corresponding to the flux density calculated from the International Commission on Non-Ionizing Radiation Protection (ICNIRP, [2]) basic restriction of 10 mA/m^2 [3]. Phase I investigated non-invasive physiological and neurophysiological indicators during and after one hour of exposure. The second step of this program (Phase II) was based on the exposure limit proposed by the Institute of Electrical and Electronics Engineers (IEEE) in a controlled environment (2.71 mT, [4]). The effects of a 3 mT exposure level (still at 60 Hz) on human cognitive functions and functional brain activity were thus studied. Here, we are summarizing Phase I results, reporting the up-to-date Phase II results and presenting our strategy for Phase III over the next 3 years.

MATERIALS AND METHODS

The procedure in Phase I consisted of collecting data from electroencephalography (EEG), standing balance (force plate), finger tip physiological tremor (laser), heart rate and heart rate variability (ECG), peripheral blood perfusion (laser Doppler), and rhythmic motor control (3D tracking system) before, during and after one hour of MF exposure (60 Hz, 1.8 mT) in 71 volunteers. Phase II consisted in testing the effect of an hour exposure to a 60 Hz, 3 mT MF on 1) the cognitive performances of 99 healthy volunteers measured by 10 validated psychometric tests (whole body exposure) and 2) human functional brain activation measured by fMRI (ASL at rest, BOLD during a finger tapping task, BOLD during a mental rotation task) in 21 healthy volunteers (head only exposure produced by the MRI scanner, 3T Verio, Siemens).

RESULTS

Phase I results did not show any significant effect of one hour of exposure on human EEG,

cardiovascular parameters or voluntary movement production. However, a significant increase in tremor amplitude was shown during exposure. Moreover, an interesting significant decrease of natural standing balance oscillations (in both amplitude and velocity) was found in the exposed condition with eyes closed, consistent with the findings of an previous study from our group. Two experiments were conducted in Phase II. Experiment 1 did not show any performance modulation due to the 3 mT exposure in 9 over 10 analyzed psychometric tests. However, one of the indices, indicated an abolition of the learning effect associated with repetition of a memory task (digit span forward). First, experiment 2 demonstrated, using a mental rotation task, a reduction of BOLD activation in regions corresponding to visual attention (after "exposure" as compared to after "sham"). This suggested a facilitation of visual attention processes. Second, we have shown using a finger tapping task that, after 1 hour of exposure, task-induced brain activation was higher in the somatosensory motor cortex and in the cerebellum as compared to "sham", suggesting an improved haptic sensitivity (i.e., improved tactile perception). This last result at 3 mT is crucial since it is consistent with a similar experiment we have previously performed at 1.8 mT. Finally, Arterial Spin Labeling (ASL) was used to image brain blood flow at rest, before, and after the hour of exposure. ASL results will be reported at the conference.

CONCLUSIONS

At 60 Hz, MF effects found on human cognition are persistent after the exposure offset and seem to interfere with learning processes at 3 mT. This suggests an effect on synaptic plasticity and should be further investigated through learning protocols. A simple motor task can be modulated during (tremor and standing balance, 1.8 mT) and after (tapping, both 1.8 and 3 mT) MF exposure. The MF seems to interact with perceptive pathways (proprioceptive and vestibular systems). However, a reliable effect has not been found yet. Magnetophosphenes are often reported as well-established consistent effects of ELF MF exposure on humans. They can be induced by intermittent MF exposure (5-20 mT depending on frequency: 5-60 Hz) [5]. Phase III is being set up to test the effects of a 60 Hz MF of up to 50 mT (local cortical and global head exposures) on magnetophosphenes perception, using EEG and fMRI (sequentially and simultaneously, EEG during exposure), evoked related potentials, tremor, and standing balance to detect a threshold for reliable responses.

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