Acute Effect of a 60 Hz Magnetic Field of up to 100 mT on Human Neuromotor Control: an EEG/EMG/Tremor Study

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Summary

OBJECTIVE: Quantify the acute impact of a 60 Hz magnetic field (MF) up to 100 mT on human neuromotor control.
METHODS: Postural tremor, electroencephalography (EEG), and electromyography (EMG) collected during 55 MF conditions (from 0 to 50 mT, 5 mT increments, 5 s each) at 60 Hz. Additional experiment up to 100 mT undergoing.
RESULTS: Decrease of the EEG mu rhythm (8-12 Hz) spectral power with increasing MF flux density in the left primary somatosensory cortex, responsible for tactile perception.
CONCLUSIONS: Pilot results acquired with exposure up to 50 mT do not produce a functional outcome, despite a small but significant decrease in EEG mu rhythm. Additional results under exposures up to 100 mT will be presented at the conference.

Abstract

Introduction

Humans experience numerous sources of daily exposure to extremely low frequency (ELF, < 300 Hz) magnetic fields (MF) such as high voltage power lines, industrial processes (such as welding), and domestic electric appliances. To investigate potential effects of ELF MF exposure on humans, different strategies to measure physiological, neurophysiological and behavioural outcomes have been used in the literature. For example, researchers investigating electroencephalography (EEG) have reported that ELF MF can increase the resting occipital alpha rhythm (8-12 Hz) [1, 2]. Other behavioural studies have reported modulations induced by ELF MF exposure, such as a reduction of anteroposterior standing balance oscillations [3-5] or a decrease of physiological tremor amplitude [6].

This study will examine possible ELF MF effects on human neuromotor control with regards to postural tremor, EEG, and electromyography (EMG). Postural tremor (one way to evaluate physiological tremor) refers to tremor produced while maintaining a stable position against gravity. The EEG rhythm usually studied in MF exposure research, corresponds to brain waves between 8 and 12 Hz (alpha rhythm) and primarily originates in the occipital brain region. Such waves (8-12Hz), when recorded in the motor cortex, which is involved in the generation of physiological tremor [7], are called EEG “mu” rhythm. Interestingly, this EEG characteristic is correlated with motor activity and tactile perception [8, 9]. Previous literature has mainly studied exposure levels in the microTesla range and has not reported a threshold for reliable acute effects. In this investigation our intention is to target higher levels of exposure (i.e., up to 100 mT at a power frequency – a first in terms of neurophysiological human studies) aiming to identify a threshold above which the MF exposure modulates the tremor pathways in a replicable way. In a recent study, a non-invasive technique called transcranial alternating current stimulation (tACS) delivered alternating currents (in the ELF range) to the brain, eliciting tactile sensations in the hand contralateral to the exposure.[10]. More interestingly, using the same technique, Brittain et al. reduced the size of pathological tremor in patients with Parkinson's Disease by 50% [11]. This is of particular interest to us since the level of electric fields in the brain generated by this technology is in the order of 0.3 V/m [12], which corresponds to levels achieved by a 60 Hz MF exposure up to 100 mT.

We therefore hypothesize that, if a MF exposure can actually modulate motor cortex electrical activity, it should in cascade, impact the EEG mu rhythm, the electrical activity of the muscles (EMG) controlled by the motor cortex, and subsequently subtle background motor output such as physiological tremor.

Methods

Procedure

Ten healthy volunteers (age: 23.8 ± 4) were tested in a protocol approved by the Health Sciences Research Ethics Board (#103066) at Western University (London, ON, Canada). After confirming the participants met the inclusion criteria and provided informed consent, they were fitted with the MRI-compatible EEG cap and EMG MRI-compatible bipolar electrodes on their dominant forearm (Neuroscan-Compumedics Inc., Melbourne, Australia), wrist, and hand.

Participants sat in a comfortable armchair while exposed to various MF conditions; physiological postural tremor, EEG, and EMG were measured simultaneously (Figure 1). Postural tremor was measured using a laser system pointing vertically on the extended dominant index finger (Micro laser sensor LM10, series ARN12821, Matsushita Electronic Work, Ltd., Osaka, Japan). The exposure coil was oriented so the MF exposed the motor cortex contralateral to the participant's tested index finger (coil position centered on the C3 EEG electrode for all participants). The exposure system produced MF exposure between 0 and 100 Hz up to 50 mT_{rms} at 2 cm from the coil face. While sitting with their eyes closed in a dark room, each participant underwent 11 MF flux density conditions (from 0 to 50 mT, 5 mT increments, 5 s each). The flux density conditions were each repeated 5 times (computer-driven double-blinded randomized order [13], separated by 5 s without exposure). A second group of participants is currently being tested up to 100 mT_{rms}.

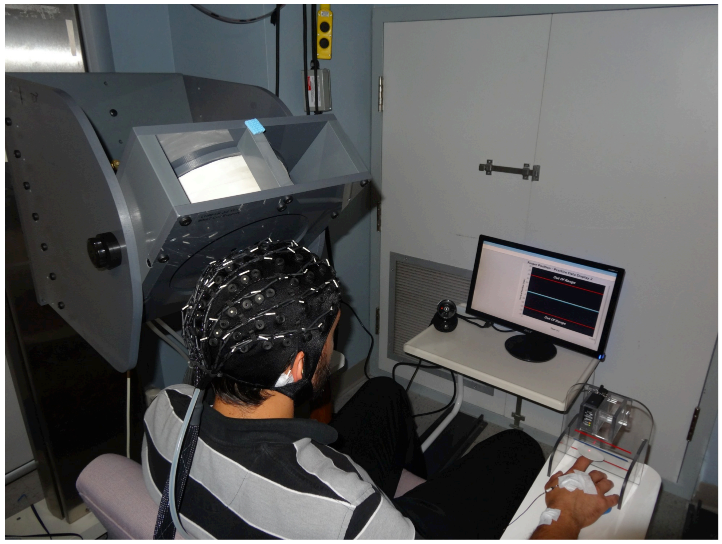

Figure 1: Participant with EEG cap and EMG electrodes. Postural tremor is recorded from the dominant index finger positioned according to the visual feedback (blue line on the LCD screen) from the laser sensor. The beam of the laser is pointing down in the middle of a white cardboard taped on the finger.

Measured Variables and Statistical Analysis

For postural tremor five validated tremor characteristics were studied: amplitude, drift, dominant frequency, median frequency, and power in the 8-12 Hz frequency range. EEG mu rhythm (8-12 Hz) spectral power was calculated from the electrodes (C1, C3, C5) covering the left primary motor cortex and the left primary somatosensory (CP1, CP3, CP5) cortex. The average spectral power in the 8-12 Hz frequency band was also calculated for EMG activity of the extensor digitorum communis and flexor digitorum superficialis muscles (both controlling the index finger tested for tremor [14]). A within subjects ANOVA was conducted on each tremor, EEG and EMG characteristic (1 modality = MF, 11 conditions = 0 to 50 mT).

Results

Results showed no significant main effect of MF exposure conditions on any of tremor characteristics or on the EMG power in the 8-12 Hz frequency band. In terms of EEG, among the six electrodes of interest, four did not show any significant main effect (C1, C3, C5, CP1: $F = .85$ to 2.42, $p > .05$). However, a significant main effect was found for CP3 ($F = 3.54$, $p < .05$) and CP5 ($F = 2.98$, $p < .05$, Figure 2) with both electrodes showing the same trend. It is interesting to note that there was a general trend towards a reduction of mu rhythm spectral power with increasing MF flux density. This was confirmed by a post-hoc paired t-test comparison showing a significant difference between the mu rhythm spectral power in the 0 mT and the 50 mT conditions ($t = 3.32$, $p < .05$).

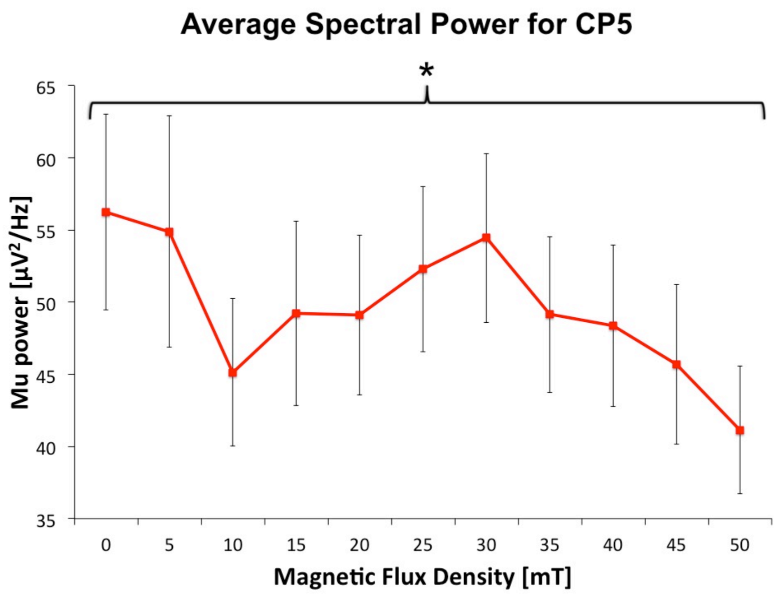

Figure 2: Ten-subjects averaged mu rhythm (8-12 Hz) power in the CP5 electrode for each MF exposure condition (from 0 mT to 50 mT). Error bars represent the standard error of the mean. This illustrates the trend towards a decreased mu rhythm with increased flux density.

Discussion

Overall, the MF exposure at 60 Hz between 0 and 50 mT did not induce any effect on the physiological tremor characteristics, nor were there any effects observed on the electrical activity of the two muscles tested. These two results suggest that, if the MF exposure had an effect on sensorimotor/motor cortex activity, it did not translate into an associated motor outcome. Interestingly, this follows the results from the EEG showing no effect in the 3 electrodes (C1, C3, and C5) located over M1, the region of the motor cortex responsible for motor control in the tested index finger. However, the 3 electrodes located over S1 (involved with tactile perception) show a tendency towards a decrease of the mu rhythm with increased MF flux density (significant for CP3 and CP5 while approaching significance for CP1). Interestingly, a functional outcome from electrical stimulation to these brain regions has been found in studies using tACS. Examples of functional effects of tACS are a modulation of tremor in Parkinson's patients following motor cortex stimulation [11] or a tactile sensation due to sensorimotor cortex stimulation in the 10-14 Hz and 52-70Hz frequency ranges [10]. It is possible that the induced electric fields produced by the 50 mT stimulus are not a sufficient dose to elicit acute modulation of the motor outcome and this is our motivation to test stimulations up to 100 mT at 60 Hz. Note that, this pilot work has only investigated a local cortical 60 Hz exposure, and does not address the question of the neurophysiological frequency-dependant response, or of the impact of a global head exposure. This work is part of a wider research program designed to experimentally establish thresholds for acute human neurophysiological responses. Current findings contribute to the overall program objective: providing international agencies establishing guidelines regarding electromagnetic field exposure with solid theoretical and experimental data acquired in human subjects [15, 16], and considering the potential to extend the scope of the findings into possible translational applications.

Conclusion

These results are the first from human electrophysiological (EMG and EEG) activity during a 60 Hz MF exposure up to 50 mT_{rms} (with flux densities up to 100 mT_{rms} currently being tested and to be presented at the conference). This was made possible through the use of MRI-compatible EMG leads, EEG caps and EEG amplifiers. The findings reveal a possible effect of 60 Hz MF exposure in the high milliTesla range on the brain region responsible for tactile perception (S1), which does not translate into any functional outcome at 50 mT. The current developments of this study are testing if a stimulus reaching 100 mT at 60 Hz will reach or exceed the threshold eliciting a tremor modulation.

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