Functional Magnetic Resonance Imaging of the Effects of a 60 Hz 3000 µT Magnetic Field on Resting State Brain Blood Flow

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Introduction The Institute of Electrical and Electronics Engineers (IEEE) has recommended a maximum level for human Magnetic Field (MF) exposure of 2700 µT at 60 Hz, the power line frequency in North America[1]. Previous human studies on MF exposure have demonstrated that Extremely Low Frequency (ELF, < 300 Hz, 50-60 Hz) MF can modulate human neurophysiology, including cognitive functions[2,3]. This work, to the best of our knowledge, is the first study to investigate the effects of a 60 minute, 60 Hz, 3000 µT MF exposure on resting state brain blood flow with ASL.

Materials and Methods Fourteen, healthy right-handed subjects (age = 25.3 ± 5.7; 7 females, 7 males) were recruited from the university community. Informed written consent as specified by the University of Western Ontario Health Sciences Research Ethics Board (#119565E) was obtained from each subject before a 2-hour session in a 3.0 Tesla research MRI (Siemens/Verio Erlangen, Germany). Each session began with the acquisition of a structural T_1-weighted anatomical image for fMRI data registration (MP-RAGE; TR = 1900 ms, matrix = 256 x 256, 176 slices, 1 mm isovoxel). Subjects then completed three pre-exposure tasks including resting state blood flow, where subjects were asked to close their eyes, relax and let their minds wander. The resting state blood flow data was acquired with a DW-ASL sequence, which incorporated pseudo-continuous ASL (pCASL), background suppression (BS) and twice-refocused spin-echo diffusion weighting[4]. The pCASL labeling/control duration was 1.5 s, consisting of 1600 Hanning pulses (peak/average B1=5.3/1.8 µT, duration=500 µsec and peak/average G=6.0/2.3 mT/m). Acquisition parameters were FOV=24 cm, matrix=64 x 64, bandwidth=3 kHz/pixel, 7/8 partial k-space, acceleration factor=2, TR =3.5 s, TE=48 ms. Subjects then underwent a 60-minute rest period within the MRI, during which the participant was either exposed to a sham condition (7 subjects) or a 60 Hz, 3000 µT sinusoidal MF (7 subjects) created by the Z gradient coil. The greatest intensity of the MF was at the top of the cortex (1 cm below the top of the skull) with a linear gradient to the null point at isocentre (first cervical vertebrae). An audio clip mimicking the sound of the ELF MF was played for the sham group during this period to ensure a similar auditory environment for both groups during the rest period. The resting state task was repeated post-exposure. Upon completion of the study, participants completed the Field Status Questionnaire (FSQ)[5] to determine if the subjects were aware of their exposure condition.

ASL data was analyzed with Statistical Parametric Mapping software (SPM8, Wellcome Department of Imaging Neuroscience, University College, London, UK, http://www.fil.ion.ucl.ac.uk/spm). Images for each subject were realigned, reoriented, coregistered, normalized to the T_1-template image and smoothed (8x8x8 mm kernel). Contrast images from a first level analysis were used in a random effects group analysis. Areas of significant activation were identified at the voxel level for $p < 0.05$, applying a minimum cluster extent size of five contiguous voxels. To determine statistically significant differences in resting blood flow between the sham and exposure groups, a comparison was conducted with a two-sample t-test of contrast images from the seven subjects included in both groups. Areas with significantly different blood flow were identified using a cluster extent threshold (5 voxels), $p < 0.001$ corrected for multiple comparisons.

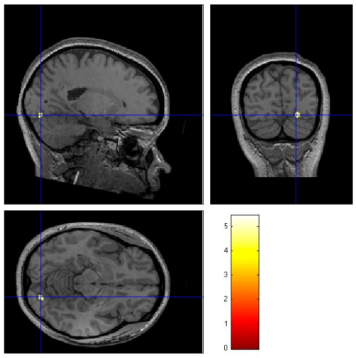

Figure 1. Increased activation in the right occipital lobe of the real exposure group.

Regions	Voxel Z	Pcorrected	x,y,z
Right posterior lobe*	3.60	0.000	18,-78,-12
Left temporal lobe*	3.66	0.000	-42,-44,-18
Left occipital lobe	4.02	0.000	-14,-84, 16
Left precuneus	3.25	0.001	-12,-62, 30
Left corpus callosum	3.35	0.000	-16,-44,-12

Table 1. Activation sites for resting state blood flow after magnetic field exposure. * indicates real exposure group

Results The Field Status Questionnaire results showed that subjects in both exposure groups could not determine their MF exposure condition (FSQ: $\chi^2 = 0.000$, $p > 0.05$; level of certainty = 2.6 out of 5). The two sample t-test of the contrast images revealed significantly higher resting blood flow in the real exposure group (post-exposure) in the right occipital lobe (Figure 1.) and left temporal lobe; whereas significantly higher resting blood flow was found for the sham exposure group (post-exposure) in the left corpus callosum, left occipital (cuneus) lobe and left precuneus (see Table 1.). All of these brain regions are part of the resting state network.

Discussion These results demonstrate that ASL is a valuable tool to investigate the effects of ELF MF exposure (here, a 60 minute, 60 Hz, 3000 µT MF) on brain resting blood flow. The differential increase in resting blood flow observed in the two groups suggests that MF exposure has a selective effect on specific regions involved in the resting state network. Although no previous work has used ASL to observe the effects of MF exposure on the resting state network, a study by Cook et al.[6] using EEG to study the resting state found that exposure to a 15 minute pulsed MF (0-500 Hz) did have an effect on the resting state network, specifically an increase in alpha activity (8-13 Hz) in the occipital and parietal regions. Additional sessions are required to further explore the results of this pilot study and to determine the duration of MF exposure effect.

References

[1] IEEE, P1555/D5, *IEEE:* NY, 2001. [2] Cook et al., *Bioelectromagnetics* 2002;23(2):144-57. [3] Preece et al., *Int J Radiat Biol* 1998;74(4): 463-70. [4] Wang et al., *Proc ISMRM* 2010. [5] Cook et al., *Bioelectromagnetics* 1992;13(4):261-85. [6] Cook et al., *Bioelectromagnetics* 2004;25(3):196-203.