Measurement of Visual Evoked Potential During and Following Exposure to Switched Magnetic Fields

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Introduction: The aim of this experiment is to examine the effect of exposure to typical MRI switched magnetic fields on the visual evoked potential (VEP) response of a human subject, without the presence of a high static magnetic field and confounding acoustic noise. The magnitude and frequency of the fields used were similar to those used in a typical MR imaging sequence. In a new Physical Agents (Electromagnetic Field (EMF)) Directive, the European Union has recently introduced occupational limits for exposure to alternating magnetic fields. This directive could have a large impact on MRI applications, especially interventional procedures. In an ongoing discussion in the international scientific literature concerning the scientific evidence on which these limits are based [1-4], it has been argued that the knowledge concerning such exposures is too limited and additional studies assessing effects of exposure to EMFs on humans should be conducted. One of the main contributions to the establishment of limits was carried out by Silny [5] who demonstrated long term reversal of the P100 VEP polarity at 60mT amplitude and 50Hz exposure. No mechanism or explanation for this effect is offered in his paper. The experiment described here aims to replicate this work and determine if any long term or reversal of VEP is present, but using a magnetic field amplitude and frequency more representative of MRI.

Experimental: The experiment took place away from any static magnetic field to avoid any confounding effects of the static field (such as the vertigo effect) or also any acoustic noise. The gradient field was created using an in-house designed and built magnetic gradient coil that was mounted on a gantry with its z-axis vertical. The required waveform was generated by an in-house built waveform generator controlled by a computer and then amplified by a pair of Amcron (Crown Inc., Elkhart, IN, USA) power supplies wired in parallel and used in current mode. The volunteers were seated upright on a chair that was fixed to a variable height platform, to ensure that the head was positioned within the coil in such a way that the transverse plane of the head level with the eyes was exposed to the maximum switched magnetic field generated by the coil. The subjects had a good visual access to an LCD screen which was positioned ~40 cm from the eyes. The gradient coil generated a sinusoidal alternating magnetic field with a frequency of 490 Hz for 250 cycles (0.5 seconds) which was repeated every 5 seconds. The total duration of each exposure was 10 minutes (600 cycles). The magnetic field used was 20 mT/m r.m.s with a peak slew rate of 87 T/m/s. Peak-exposure to the magnetic field (B) and to switched magnetic fields at eye-level (approximately 10 cm from the centre of the coil) was 2.8 mT and 8.7 T/s during the exposure period. Inter-wire forces caused the coil to make a faint sound when the gradient was switched, which might have been detected by the subjects. Therefore a 490 Hz masking tone was played in the room, and the subjects were given ear defenders (>30 dB at 500Hz and containing no metal parts) to wear. The VEP was recorded by a using an MR compatible 32 channel BrainVision recorder (Brain Products, Munich, Germany). Ag/AgCl electrodes were placed according to10-20 international system keeping impedances less than 15 kΩ. Data was collected at a rate of 5 kHz. A 2 Hz reversal, 8 x 8 checkerboard, occupying 20 degrees of the visual field was presented on the screen using Presentation software (Neurobehavioral Systems, Albany, CA). A trigger pulse was passed to the EEG recording. The gradient waveform was free-running with respect to the VEP acquisition which lasted for 3 minutes per measurement point. A separate VEP measurement was started every 5 minutes. The experimental protocol used is shown within Fig 1 with 2 periods of 10 minute gradient exposures separated by 10 minutes as depicted by the shaded box. Seven subjects were recruited (5 male, 2 female, age 27 ± 12 years) for this study and local ethical approval was obtained.

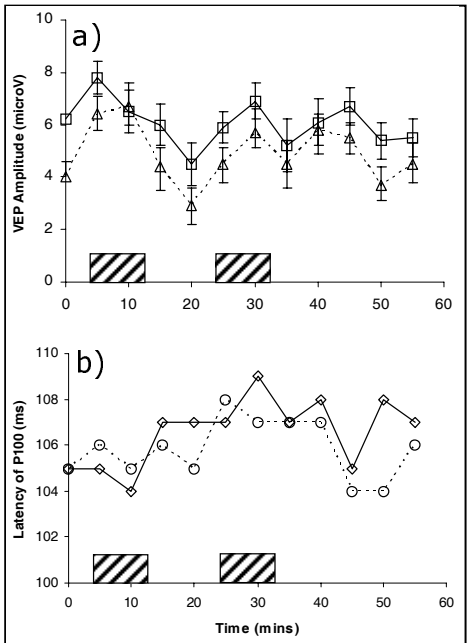

Figure 1: a) VEP P100 O1 (squares) and O2 (triangles) amplitudes are shown (upper graph). b) Latencies in P100 peak for O1 (diamonds) and O2 (circles).

Results: Data processing (using BrainVision Analyser) followed the following protocol: data were segmented for each measurement; artefact and noise rejection was performed including removal of acquisitions affected by gradient switching; and band-pass filtered (0.1 – 40Hz). No attempt was made to retrieve VEP data during actual applied gradient field periods because the subject's head was not restrained which precluded the generation of an accurate correction template. However, due to the low duty cycle of 0.1, the number of events lost was only ~70 out of 360. Occasionally there were bursts of external environmental noise as the experiment was not within a screened room so these events were rejected as well. In two extreme cases, this resulted in one whole VEP acquisition in the sequence being lost. A typical sequence is shown in Fig 1 for subject 4. Both VEP P100 O1 and O2 amplitudes are shown (upper graph) together with the latencies of these P100 peaks (lower). SEM uncertainties are shown for the amplitudes but are not available from the analysis software for latency. No obvious trend or response is detectable in any of the subjects' responses. A t-test is performed to assess the significance of any difference in the mean values of O1 and O2 P100 amplitude during exposure compared to no exposure. P-values for this test for all subjects is shown in Table 1 where the only possible significant response is subject 4 (Fig 1).

Discussion: No evidence has been found for any significant changes in VEP either during or immediately after exposure to switched magnetic field for our subjects. There was no polarity change or discontinuity in the VEP temporal record. No changes beyond random fluctuations or gradual changes were observed. Only one subject's response showed a significant correlation with the field exposure but this appears to be an increase and not a suppression of VEP –and altogether contrary to the assertion in ref [5]. It is unlikely that more complex analyses would produce any statistical significant result e.g. using a delayed or convolved exposure function. Although the peak magnetic fields reported here are lower than in ref [5], the frequency used here is higher resulting in very similar peak current densities (estimated to be of order 100mA/m^2) within the brain. For the rest trials the relative error in amplitude was approximately 20%, so that this study was adequately powered to detect the inversion of VEP amplitude reported by [5] and would have had a 50% chance of detecting a 40% decrease in any individual subject

Subject	O1 p-value	O2 p-value
1	0.27	0.21
2	0.21	0.16
3	0.37	0.43
4	0.02	0.03
5	0.46	0.43
6	0.41	0.1
7	0.45	0.41

Table 1: P-values of significance in difference of mean P100 VEP amplitudes between exposure on and off periods.

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