Mapping epileptic networks using simultaneous EEG-MRI at ultra-high field

Frédéric Grouiller[1], João Jorge[2,3], Francesca Pittau[4], Pascal Martelli[1], Wietske van der Zwaag[5], Christoph M. Michel[6], Serge Vulliémoz[4], Maria Isabel Vargas[1], and François Lazeyras[1]

[1]Department of Radiology and Medical Informatics, Geneva University Hospital, Geneva, Switzerland, [2]Department of Bioengineering, Institute for Systems and Robotics, University of Lisbon, Lisbon, Portugal, [3]Laboratory for Functional and Metabolic Imaging, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland, [4]EEG and Epilepsy Unit, Department of Neurology, Geneva University Hospital, Geneva, Switzerland, [5]Biomedical Imaging Research Center (CIBM), Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland, [6]Functional Brain Mapping Laboratory, University of Geneva, Geneva, Switzerland

Target audience: neuroscientists, engineers, neuroradiologists and epileptologists interested in simultaneous EEG-fMRI.

Purpose: The possibility to record simultaneous EEG-fMRI at ultra-high field offers the opportunity to better characterize the dynamics of epileptic networks with a great sensitivity. However, most of the artefacts induced by the MR environment on EEG (gradient and pulse artefacts, vibrations induced by the Helium pump, etc) are proportional to the static field strength[1]. The aim of this study was to demonstrate that using an optimized setup and appropriate artefacts reduction algorithms, EEG data acquired at ultra-high field is of sufficient quality to detect the epileptic network. To our knowledge, this is the first report of simultaneous EEG-fMRI acquisition in epileptic patients at ultra-high field.

Methods: Three patients (3 males, mean age = 20 y.o., range = 18-22 y.o.) with lesional pharmacoresistant epilepsy were included to perform a simultaneous EEG-fMRI recording at ultra-high field. The study was approved by the local ethics committee and the patients gave their written informed consent.

Data acquisition: Simultaneous EEG-fMRI data were acquired during 20 minutes at rest with eyes closed in a 7T MR-scanner (Siemens) equipped with an 8-channel transmit/receive head coil. EEG was acquired at 5kHz using two MR-compatible amplifiers (Brain Products) connected to a 64-channel cap (EasyCap). EEG acquisition was synchronized with the MR clock to facilitate removal of gradient artefacts and an optimised setup was used with ultra-short bundled cables to reduce the environmental noise[2]. Six hundred functional images were acquired using T_2^*-weighed single-shot gradient-echo echo-planar images (TR=2000ms, TE=25ms, voxel size=1.5x1.5x1.5mm^3, 32 slices).

Analysis: EEG was corrected for gradient and pulse-related artefacts using the moving average template subtraction method. Pulse artefacts were detected using an estimated ballistocardiogram signal calculated as the difference between the averaged EEG signals of a subset of electrodes on the right and on the left anterior temporal and facial regions[3]. Pulse artefact residuals were removed using temporal independent component analysis. An experienced neurophysiologist manually detected interictal epileptiform discharges (IEDs) and a patient-specific epileptic topographic map was built by averaging IEDs detected in the clinical EEG acquired outside MRI. The presence of this epileptic topographic map was quantified by means of correlation-based fitting[4]. The IEDs timing or the time course of the topography-based correlation was then convolved with the canonical haemodynamic response function and used as a regressor for the fMRI analysis.

Functional MRI images were motion corrected, co-registered onto a high resolution 3D T1-weighed structural image and spatially smoothed with an isotropic Gaussian kernel of 4 mm full width at half-maximum. Functional time-series were analysed voxel by voxel with a general linear model (SPM8, Wellcome Department of Imaging Neurosciences, University College London). IED-related and patient specific topography-related haemodynamic changes were detected using a paired t-test ($p<0.001$, extent threshold: 20 voxels).

Results: After gradient and pulse artefacts removal, IEDs were successfully detected on the corrected EEG in one patient with left occipital dysplasia (Patient 1, Fig. 1). The two other patients had very rare IEDs that could not be detected during the 20 minutes of simultaneous recording. For two patients (Patients 1 and 3), the presence of IED during the clinical EEG allows to build a patient-specific topographic map. Topography-related and IED-related haemodynamic changes are comparable (Fig. 2) attesting that the quality of corrected EEG is good enough to perform topographic analyses. Functional activations were concordant with the anatomical lesion and the electro-clinical findings. As reported in previous recording in healthy subjects[2], susceptibility artefacts due to the presence of the EEG cap is minimal.

Discussion & Conclusion: Epileptic network localisation using simultaneous EEG-fMRI with an optimized setup to reduce environmental noise and appropriate artefacts removal algorithms is feasible at ultra-high field. The EEG quality allows performing noise-sensitive analyses such as EEG topography spatial correlation. These results open new perspectives to better characterize epileptic networks at higher field with higher spatial resolution and better BOLD sensitivity than at 3T.

References: (1) Debener S. et al., Int. J. Psychopysiol., 2008. (2) Jorge J. et al., Neuroimage, 2015. (3) Iannotti G.R. et al., Brain Topography, 2014. (4) Grouiller F. et al., Brain, 2011.

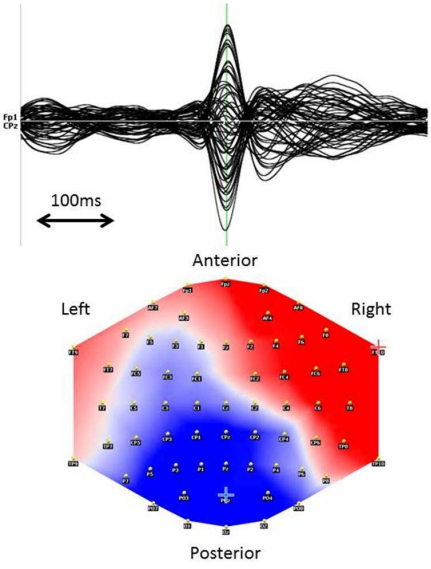

Fig. 1: Averaged IED obtained during simultaneous recording of Patient 1 (upper row) and corresponding topographic map (lower row).

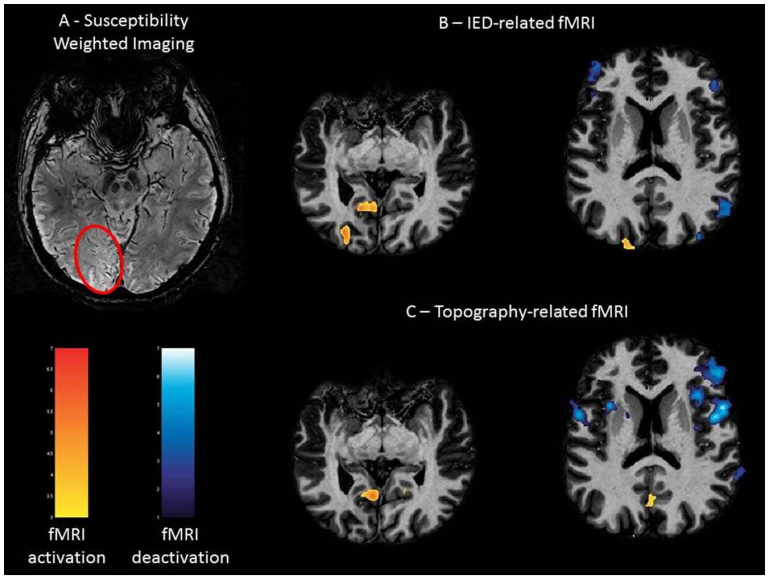

Fig. 2: (A) Susceptibility Weighted Imaging showing left mesial occipital dysplasia in Patient 1. (B) IED-related fMRI activation in left mesial occipital (red) and deactivation in a physiological resting state network (blue). (C) Topography-related fMRI showing the similar network than with IED-related analysis.