Functional QSM at 9.4T with single echo gradient-echo and EPI acquisition

Dávid Balla[1], Philipp Ehses[1,2], Rolf Pohmann[1], Juliane Budde[1], Christian Mirkes[1,2], G. Shajan[1], Richard Bowtell[3], Klaus Scheffler[1,2]

[1]High-field MR Centre, Max Planck Institute for Biological Cybernetics, Tübingen, Germany, [2]Department of Biomedical Magnetic Resonance, University of Tübingen, Tübingen, Germany, [3]Sir Peter Mansfield Magnetic Resonance Centre, University of Nottingham, Nottingham, United Kingdom

Background/Purpose: Functional QSM (fQSM) was recently proposed for the analysis of gradient-echo (GE) BOLD contrast acquired using zoomed EPI time-series at 7T [1,2]. Here we present fQSM and fMRI activation maps, obtained at 9.4T from full coverage GE-EPI and single echo "shifted" gradient-echo (esGRE) [3] experiments. The goal of this project was to test different acquisition strategies and optimize MR parameters for fQSM at 9.4T.

Methods: Experiments were performed on a 9.4T system equipped with a custom-built 16-channel transmit-coil and a 31-channel receive-array helmet [4]. The visual stimulation for fMRI consisted of a flickering checkerboard disk stimulus on a grey background. The motor-task was tapping of the thumbs of both hands with the four other fingers in quick cyclic runs. Both paradigms are expected to produce positive BOLD contrast in respective cortical areas in the magnitude time-series. Acquisition strategies: (1) esGRE sequence with interleaved slices [3] providing distortion-free T2*-weighted images with a TE of 18.7ms and a TR of 90ms; further parameters were: 1mm isotropic resolution, 12 slices, volume TR = 4.32s, 140 repetitions and 3-fold acceleration; (2) gradient-echo EPI (GE-EPI) with 1mm isotropic resolution, 28 slices, TE/TR = 25ms/3s, 200 repetitions and 3-fold acceleration. Processing included the offline reconstruction of magnitude and phase images from the multichannel, accelerated raw data in Matlab, followed by phase unwrapping [5], motion correction [6], temporal filtering for EPI [7], background field removal [8] and QSM calculation with thersholded k-space division (TKD) [9]. Activation maps were calculated using uncorrected T-test with $p<0.015$.

Results: The esGRE-fQSM and GE-EPI-fQSM activation maps presented in the figure (a), (c) and (e) demonstrate high sensitivity by showing supra-threshold values that are coincident with significant voxels in the corresponding fMRI maps, (b), (d) and (f). The noise in the maps is a result of the simple statistics, which deliberately avoided clustering, spatial smoothing etc. esGRE vs. GE-EPI: Pros esGRE – high structural fidelity (specificity) of fQSM and fMRI and simple data handling after acquisition due to minimal distortions (e.g. spatial registration is unproblematic). Cons esGRE – frequent application of the excitation pulse results in in-flow effects. Pros GE-EPI – the gain in contrast sensitivity due to signal sampling efficiency and the possibility to use long echo times. Cons GE-EPI – geometrical distortions and time varying ghost artifacts render spatial registration (e.g. at high spatial scale) difficult.

Conclusion: Functional QSM is feasible for data acquired with GE-EPI at 9.4T. Relative to previous studies, we presented data with full transverse brain coverage and proposed the fast esGRE acquisition technique as a useful alternative to GE-EPI, especially for fQSM at ultra-high fields.

References: [1] Balla et al. (2012) ISMRM #325; [2] Balla et al. (2013) ISMRM #300; [3] Ehses et al. (2012) ISMRM #329; [4] Shajan et al. (2013) MRM in press; [5] Schofield and Zhu (2003) Optics Lett. 28:1194; [6] Jenkinson et al. (2002) NeuroImage 17:825; [7] Hagberg et al. (2012) Neuroimage 59:3748; [8] Schweser et al. (2011) Neuroimage 54:2789; [9] Wharton et al. (2010) MRM 63:1292

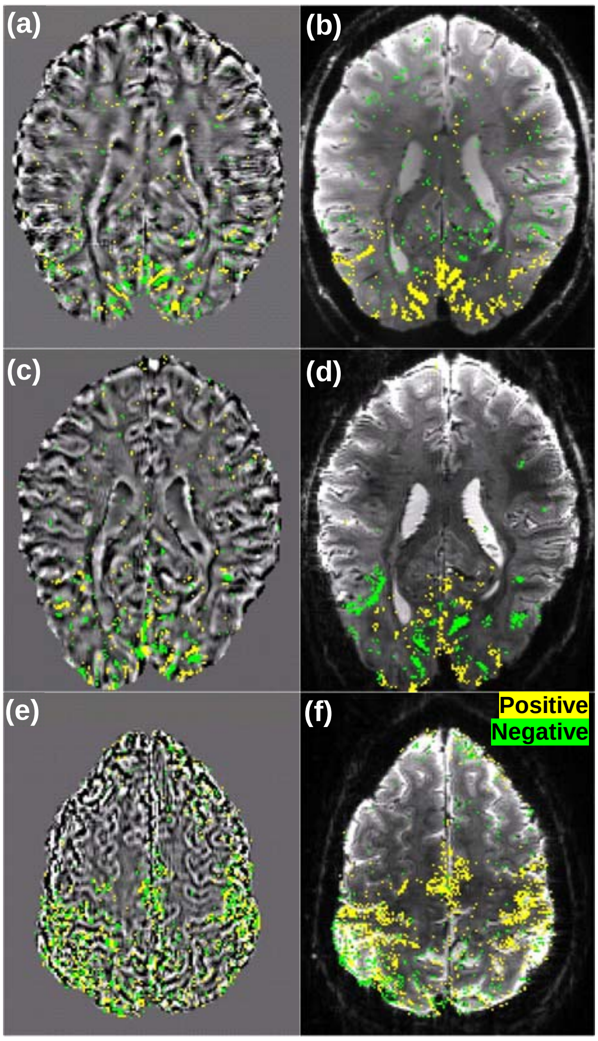

Figure: Thresholded statistical significance maps of positive (yellow) and negative (green) contrast changes, projected onto the preprocessed average of the time-series. (a) esGRE-fQSM, (b) esGRE-fMRI, (c) GE-EPI-fQSM and (d) GE-EPI-fMRI during visual stimulation (T>2.3, same slice); (e) GE-EPI-fQSM and (f) GE-EPI-fMRI during motor activity (T>4).