Systematic evaluation of BOLD fMRI phase changes at 7 Tesla

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INTRODUCTION: Although fMRI data are complex-valued, most fMRI studies today have only considered the magnitude data while discarding the phase information [1]. However, phase can carry complementary information to magnitude fMRI data [2], especially at ultra high field (UHF). A significant sensitivity gain at UHF has already been exploited in magnitude based fMRI [3] and could also improve the sensitivity to activation induced phase signal changes. The aim of our study is a systematic experimental investigation of human phase and magnitude fMRI BOLD signal changes at 7 T using motor and visual stimulation and a breath hold condition. fMRI data will be processed using a stable phase preserving reconstruction method and analyzed by a model-driven general linear model (GLM) and a model-free independent component analysis (ICA).

METHODS: fMRI experiments were performed on a 7 T whole body system (Siemens Medical Solutions, Erlangen, Germany) with a prototype gradient system (70 mT/m, 200 T/m/s) and a 24-channel head coil (Nova Medical Inc., Wilmington MA, USA). Functional MRI data were acquired using a standard GE-EPI sequence with field of view FOV = 224 x 224 mm², voxel size = 1.4 mm³ isotropic, number of slices = 37, TR/TE = 2000/23 ms, 1838 Hz/Px bandwidth and GRAPPA factor = 3. Three different paradigms have been applied: 1) finger tapping (FT) task alternating between right and left hand (block-design: 20 s ON/20s OFF), 2) visual stimulation with checkerboard (CB) inverting at 8 Hz (block-design: 20 s ON/20 s OFF), 3) breath hold (BH) condition (block-design: 20 s breath holding/40 s normal breathing). Four healthy, right-handed male subjects between 24 and 33 years participated in the study approved by local IRB guidelines. After offline EPI reconstruction, magnitude and phase data have been preprocessed in the following way: inverse 2D Fast Fourier Transform; adaptive combination method for multi-channel fMRI time series; motion correction of real- and imaginary parts of the fMRI signal, subsequently converted to phase and magnitude images; masking; image phase wrap elimination. fMRI data have been analyzed separately for magnitude and phase using a standard GLM analysis and an ICA method. GLM results have been corrected for multiple comparisons (FWE; $p < 0.0001$ for FT and CB; $p < 0.05$ for BH). Stimulation related independent components could be identified by their specific, paradigm corresponding frequency spectra and their spatial position.

RESULTS: Phase changes upon activations are of comparable sensitivity as magnitude data. Obtained overall activation patterns of magnitude and phase data have been globally similar (Fig. 1), but have revealed local differences: coincidence between magnitude and phase activation maps for FT approx. 10 % and for CB only approx. 1 %. BH led to significant activation patterns distributed over the complete fMRI volume. On average over activation maps of all experiments and subjects the calculated grey matter contribution has been 88 % for magnitude and 85 % for phase data attended by an averaged signal change of 10.9 % for magnitude and 0.33 rad for phase fMRI images. Regions with temporally correlated magnitude and phase time courses obtained via ICA method have been identified for FT and regions with temporally anti-correlating time courses have been identified for CB data (Fig. 2). Frequency spectra of almost all independent components of the phase data, except those of the BH experiment, contain signal variations in the area of the subjects' breathing frequencies and increased the signal variance.

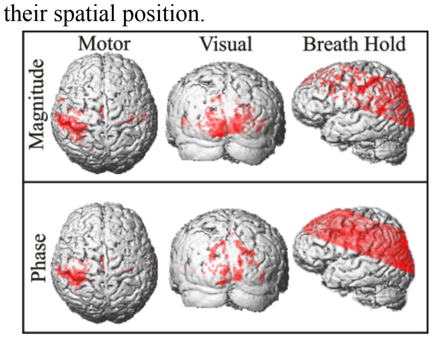

Fig. 1: GLM activation maps of magnitude and phase data of motor and visual stimulation and breath hold condition

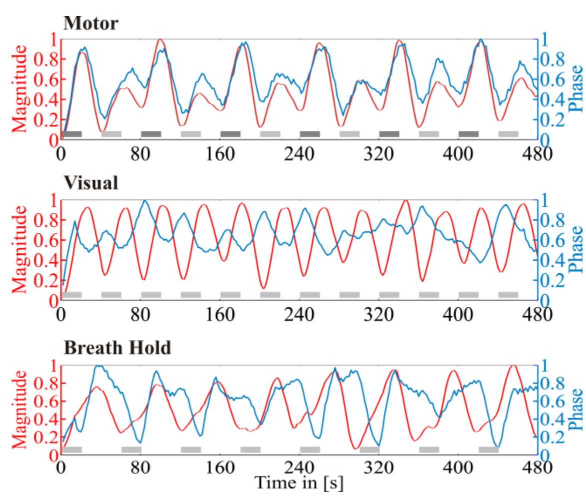

Fig. 2: ICA of magnitude and phase of motor and visual stimulation and breath hold condition; representative time courses of task related independent components

DISCUSSION and CONCLUSION: The high grey matter proportion in the obtained activation maps indicates a close spatial correlation to neuronal origin and ensures that significant activations are not associated with draining veins. ICA results verify observations from the GLM that breathing has a larger effect on the phase than on magnitude data. The dependence of the temporal correlation between magnitude and phase time courses from the specific kind of stimulation and thus from the specific activated brain region could confirm the assumption of Lee et al. [4] and He et al. [5] that phase variations are dependent on the neuronal fiber orientation. It could also confirm the assumption of Schäfer et al. [6] that phase variations are dependent on the angle of brain structure to the main magnetic field. The obtained results suggest that functional phase data may provide complementary information in fMRI analysis, may increase the detection sensitivity and should therefore be taken more into account.

REFERENCES: **[1]** Bandettini PA et al., MRM 30:161-173, 1993; **[2]** Feng Z et al., NeuroImage 47: 540-548, 2009; **[3]** Yacoub E et al., MRM 45: 588-594, 2001; **[4]** Lee J et al., PNAS 107: 5130-5135, 2010; **[5]** He X et al., PNAS 106: 13558-13563, 2009; **[6]** Schäfer A et al., NeuroImage 48:126-137, 2009