Regression of Physiological Signals Using Phase-Constrained Inverse Imaging in Functional MRI

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Introduction

Inverse imaging (InI) (1) is an extreme case of parallel imaging where all slices in one direction are merged into one and reconstruction is carried out with regularization and prior information. We reformulated the InI reconstruction framework to include phase-constrained principles (2). For phase-constrained InI (pcInI), a 3D EPI image is acquired and used as prior information as well as to estimate coil sensitivities. Signal changes with respect to a reference image are obtained with pcInI, so one can use standard analysis methods after adding the reference image and the reconstructed image for each time point to obtain time series. In this study, a moving dots paradigm is chosen to assess the location of functional activation as InI suffers from poor spatial fidelity especially in the reconstruction direction. Also, a regressor showing phase changes with respect to the reference image is obtained during reconstruction and used as a confound regressor.

Methods

fMRI data were collected using a 3T MRI scanner (TIM Trio, Siemens, Germany) with the product 32 channel head coil. A standard 2D EPI sequence using a single sagittal slice that covers the whole brain is used with the following parameters: TR/TE=50/28 ms, in-plane resolution 3.5x3.5 mm, slice thickness 154 mm. A 3D EPI reference image with the same parameters but phase encoding (44 PE steps) in the slice direction is obtained. The forward problem of parallel imaging, $y = Ax$, is transformed into $\begin{bmatrix} Re(y_1) - Re(Ex_{0,1}) \\ Im(y_1) - Im(Ex_{0,1}) \\ \vdots \end{bmatrix} = \begin{bmatrix} Re(E(x_{0,1}/\hat{x}_0)) \\ Im(E(x_{0,1}/\hat{x}_0)) \\ \vdots \end{bmatrix} \hat{x}'$ (only showing the relation for coil channel 1), E is the encoding matrix which explains the undersampling scheme. Here coil observation y_1 is replaced by the dynamic change with respect to the reference image observed by coil channel 1, $x_{0,1}$. pcInI enables to apply the forward problem twice for each channel which reduces the number of unknowns by a factor of two thereby improving the inverse reconstruction. Sensitivity maps are calculated by dividing single coil channel images by the magnitude of the reference image. With this formulation the signal change, $\hat{x}'$, is reconstructed using Tikhonov regularization and the L-curve technique is used to estimate regularization parameter. A phase regressor is obtained for each coil channel by comparing the phase of the 3D EPI reference image collapsed in the reconstruction direction with that from the undersampled data. As such, each coil channel has a corresponding phase drift which can be used as a regressor of no interest (either individually or after averaging) as it shows a time course with a dominant peak at the respiration frequency. **Functional paradigm:** stationary dots are presented on one side of the screen and moving dots on the other side, and sides are switched every 20s. Four minutes of data with six ON-OFF conditions were acquired from four subjects. Two contrasts of interest are considered: Left vs. right (red) and right vs. left (blue).

Results & Discussion

Results are presented in Figure 1. A considerably high threshold is used to remove all false positives and artifacts which are due to poor spatial resolution of InI. It is important to note that activation in one of the contrasts (blue) is visible only when using 32 individual regressors. On group average, cluster size and maximum z-scores increase 52% and 10% (average regressor) and 534% and 36% (individual regressor) with respect to the case with no regressors. Improvement by using 32 regressors is due to regionally different information in the regressors of the individual coil elements which explains the better match between data and full model for the paradigm (~0.025 Hz), principal respiration (~0.33 Hz) and second harmonic of respiration (~0.67 Hz) frequencies.

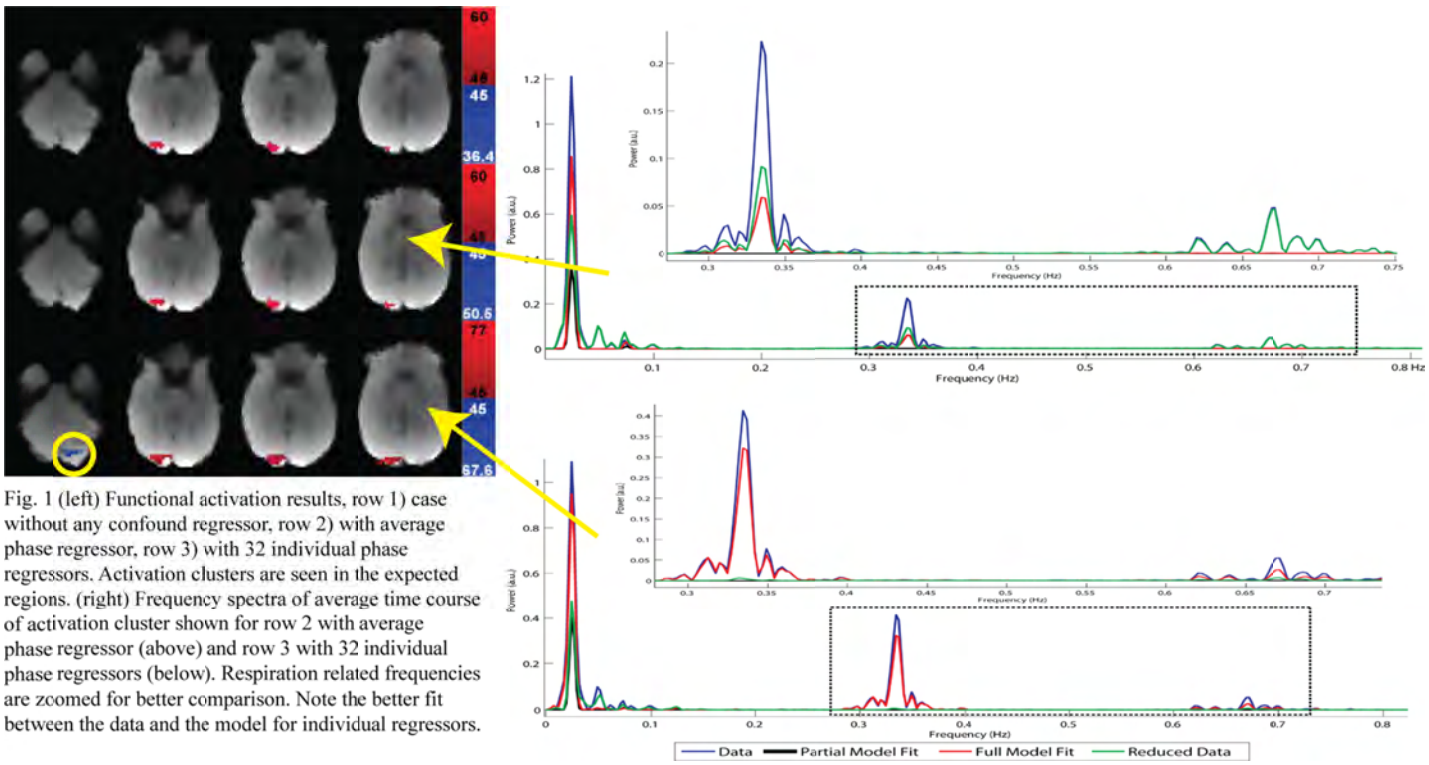

Fig. 1 (left) Functional activation results, row 1) case without any confound regressor, row 2) with average phase regressor, row 3) with 32 individual phase regressors. Activation clusters are seen in the expected regions. (right) Frequency spectra of average time course of activation cluster shown for row 2 with average phase regressor (above) and row 3 with 32 individual phase regressors (below). Respiration related frequencies are zoomed for better comparison. Note the better fit between the data and the model for individual regressors.

References

1) Lin, F.H. et al., (2006), Magn Reson Med, 56(4), p. 787-802.

2) Willig-Onwuachi, et al. (2005), JMR, 176(2),p. 187-198