Independent Component Analysis (ICA) of functional QSM

PINAR SENAY ÖZBAY[1,2], Cristina Rossi[1], Geoffrey Warnock[3], Felix Kuhn[3], Burak Akin[4], Klaas Paul Prüssmann[2], and Daniel Nanz[1]
[1]*Department of Radiology, University Hospital Zürich, Zürich, Switzerland,* [2]*Institute of Biomedical Engineering, ETH Zürich, Zürich, Switzerland,* [3]*Department of Nuclear Medicine, University Hospital Zürich, Zürich, Switzerland,* [4]*Medical Physics, University Medical Center, Freiburg, Germany*

Target Audience Researchers who are interested in fMRI, Quantitative Susceptibility Mapping (QSM), functional QSM, Independent Component Analysis (ICA)

INTRODUCTION In conventional fMRI, independent component analysis (ICA) of the signal-magnitude time course can separate statistically independent additive signal components and identify areas of neuronal activation even without knowledge of the activation paradigm. In recent years, fMRI approaches that exploit information complementary to signal-magnitude variations, such as time-course phase and susceptibility data have been of continuously increasing interest[1-7]. The purpose of this work was to investigate the potential of ICA for the identification of activated brain tissue regions based on time-series data that map variations of brain-tissue magnetic susceptibility (quantitative susceptibility maps, QSM) under a paradigm of visual stimulation, to preliminarily test effects of data filters on the weight distribution of the signal components, and to compare the results with those from traditional BOLD data.

METHODS

MRI: Gradient-echo-EPI (FA = 90, TR = 3 s, TE=35 ms, voxel dimensions = 1.8, 1.8, 4 mm) images of nine consenting volunteers were acquired on a 3T MR system (Ingenia, Philips Healthcare, Best, The Netherlands).

QSM: Unwrapped and background field corrected phase maps (SHARP, threshold = 0.2) were obtained using Laplacian-based convolution, multiplication with a binary brain-tissue mask (FSL-BET[10], threshold 0.02, eroded with a 3-pixel kernel) followed by deconvolution[8, 9]. Quantitative susceptibility maps were generated by dipolar inversion of the SHARP maps, using the relation $\Delta\chi = FT^{-1}(FT(-SHARP/\gamma B0\Delta TE)g)$, $g = 1/3 - k_z^2k^2$, $k^2 = k_x^2+k_y^2+k_z^2$, where FT = Fourier Transform, γ = gyromagnetic ratio, $B0$ = field strength, ΔTE = echo-time increment. Division by zero-values in g along the magic angles was avoided by thresholding and regularization [7]. For comparison with magnitude BOLD data, the sign of the values was inverted and the minimum value of the negated quantitative susceptibility data over the whole time series was subtracted from the data.

Visual stimulation: A block-design paradigm (15 s/block; 5 dynamics) with 8 blocks of rest conditions (grey screen with focus crosshair) alternating with 8 blocks of stimulation (black / white polar checker-board on grey back-ground, 8 Hz).

ICA: BOLD and QSM data were analyzed with the Melodic toolbox of FSL[11]. For both analyses, the time-series were de-composed into18 components, for each of which ICA yielded z-scores as output. The z-score map of the QSM-signal component, which temporally correlated best with the stimulation paradigm, i.e., of the "activation component", overlaid on anatomical images, are shown in Fig. 1. Time-courses and power-spectras of the corresponding components in the QSM and BOLD analyses are shown in Fig. 2.

Effect of Temporal Filtering: The independent component analysis was repeated with 1) unfiltered QSM data, and with the same data after applying 2) a band-pass filter with cut-off values of 0.03Hz and 0.11Hz.

RESULTS & DISCUSSION An ICA power spectrum under a visual paradigm has been presented in a previous study[1,2]. According to (1,2) and based on our paradigm, the activation component should oscillate at a frequency in the range between ~ 0.01 – 0.1 Hz, and have an intensive peak in the power spectrum. Z-score maps for this signal component as derived from unfiltered (a) and band-pass filtered (b) QSM data and from BOLD data (c, blue) are shown in Fig. 1. The z-score time courses and corresponding power spectra in the voxel at the green cross are shown in Fig. 2 a) (unfiltered QSM) b) band-pass filtered QSM) and c) (unfiltered BOLD). We observed that the area of the activation was larger and the z-score at the cross had increased from 5 to 13 with the use of band-bass filter, compare Fig. 1 a, b. In addition, with the band-pass filter the activation component had a lower non-explainable variance and the time course of the QSM data more closely correlated with the stimulation paradigm and as well with the BOLD data time course (Fig 2 (c)). In our previous work[7], SPM analyses were done for QSM and BOLD data. Although the results were also promising, ICA may yield more information about other sources of temporal signal variation, e.g., breathing or cardiac motion, unrelated to the task. ICA of QSM data might become a promising method for accurately localizing neuronal activation areas and understanding the underlying mechanisms, complementary to information drawn from BOLD data, which can be acquired in the same scan.

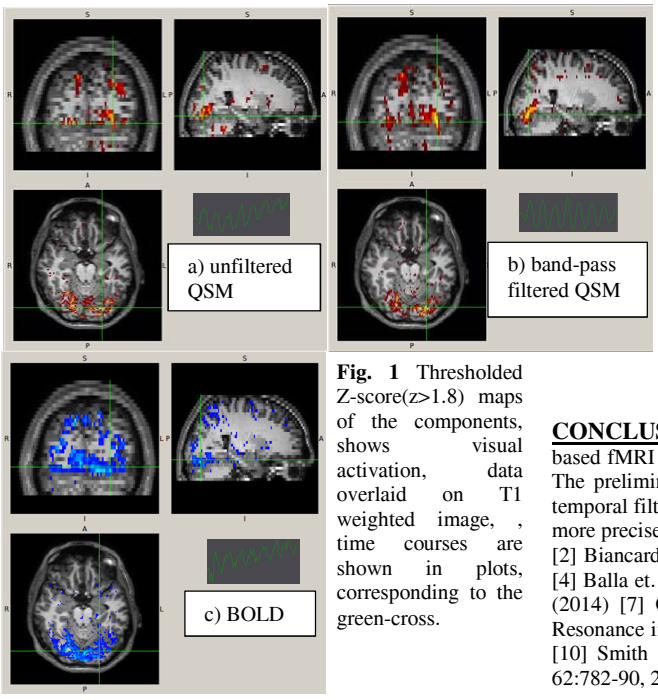

Fig. 1 Thresholded Z-score(z>1.8) maps of the components, shows visual activation, data overlaid on T1 weighted image, , time courses are shown in plots, corresponding to the green-cross.

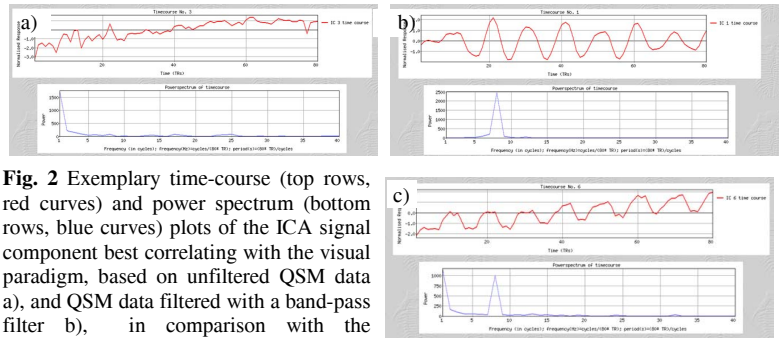

Fig. 2 Exemplary time-course (top rows, red curves) and power spectrum (bottom rows, blue curves) plots of the ICA signal component best correlating with the visual paradigm, based on unfiltered QSM data a), and QSM data filtered with a band-pass filter b), in comparison with the corresponding plot of EPI-magnitude BOLD data c).

CONCLUSION In this study, we used independent component analysis to compare BOLD and QSM-based fMRI at 3 Tesla and compared the corresponding z-score maps, time-courses and power-spectras. The preliminary results show that there is a good agreement between BOLD and QSM data and the temporal filtering helped to improve the results. Moreover by using QSM, gray matter activation may be more precisely localized.

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