Fast functional MRI using inverse imaging with dynamic off-resonance artifacts correction

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TARGET AUDIENCE: Scientists interested in dynamic monitoring and correction of B_0 drift in fMRI experiments

PURPOSE: The phase of NMR signal can drift significantly over time in fMRI experiments due to systematic instability, head motion, or thoracic/pelvic cavity motion [1,2]. Artifacts related to phase drift can be corrected by retrospective signal processing [3-6]. However, time series images can be shifted or distorted seriously such that they cannot be recovered by these methods. Navigator echoes have been proposed to correct time-invariant artifacts related to phase drifting before MRI reconstruction [7-9]. Respiration-induced phase drift can also be estimated and corrected dynamically by measuring navigator echoes in each acquisition in fMRI [10].

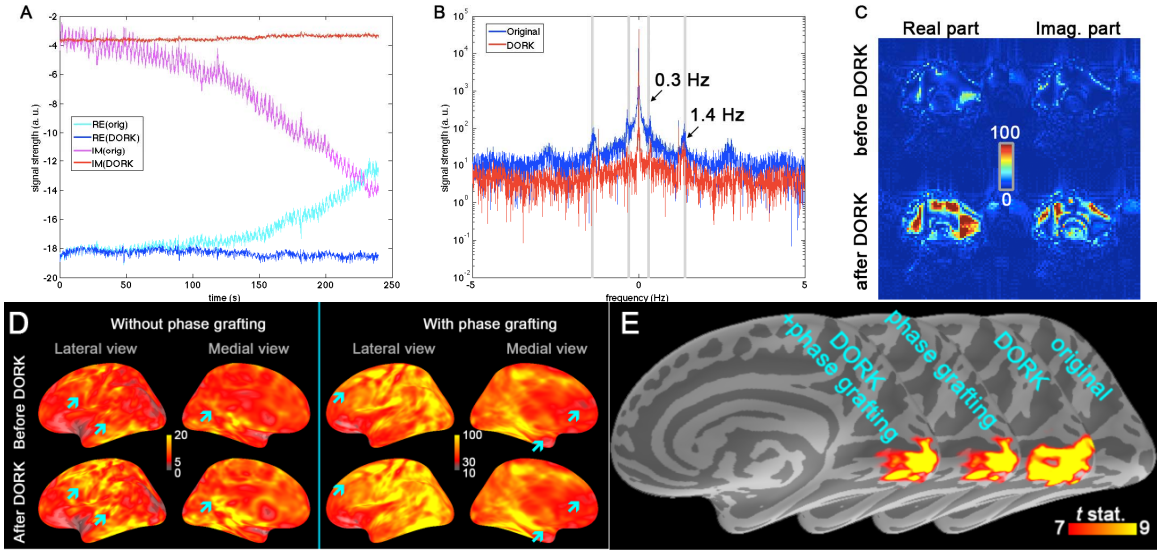
In this study, we use the "dynamic off-resonance in *k*-space" (DORK) [10] method to correct the phase drift in magnetic resonance inverse imaging (InI), which is a method using minimally gradient encoded data and parallel detection to achieve massively accelerated fMRI [11,12]. Typically one fully gradient encoded InI reference scan is measured before continuous accelerated InI measurements. The complex-valued reference scan is used to reconstruct each instantaneous InI scan lasting over minutes. As the phase of each accelerated InI scan becomes farther away from the initial value, the discrepancy between the reference scan and the instantaneous accelerated InI acquisition becomes more severe. We hypothesize that DORK can significantly improve the InI reconstructions by reducing such data inconsistency. Empirical results show that DORK can reduce the InI fluctuation in the respiratory frequencies, improve the stability of the fMRI time series, and increase the peak value of hemodynamic response estimates.

METHOD:

Four healthy subjects with written informed consent were measured a 3T MRI scanner (Skyra, Siemens Medical Solutions, Erlangen, Germany) using a 32-channel head coil array. Visual hemi-field checkerboard flashing (8 Hz reversal rate) was presented to the subject randomly over a 4-minute run. A fully gradient encoded InI reference scan was measured using a multi-shot 3D echo-volumnar imaging sequence (TR=100 ms; TE=30 ms, flip angle =30°. FOV = 256 mm, image matrix = 64 x 64). Accelerated InI scan was measured by leaving out the partition encoding (anterior-posterior direction) to achieve the10 Hz sampling rate with the whole-head coverage. Importantly, four navigator echoes were first measured in the accelerated InI scan after each RF excitation. High resolution structural images for each subject was acquired using the MPRAGE sequence.

InI reconstruction started from DOKR correction: we arbitrarily chose the first InI accelerated scan as the phase to be aligned to. At each subsequent accelerated InI scan, the phase of each echo was linearly compensated accordingly. After DORK processing, InI images were reconstructed using the minimum-norm estimate with phase constraint (PC) [13]. Reconstructions with phase constraint phase graft (PCPG), where the phase of instantaneous InI was copied from the central partition of the reference scan, were also calculated. Time-domain SNR was calculated as the ratio between the mean and the standard deviation of the time series at each image voxel. The hemodynamic responses were estimated from each reconstruction using the General Linear Model with finite impulse response basis function.

RESULTS: Figure A shows the drift of the average signal from one channel of the coil array over 4 minutes. DORK clearly stabilized the signal (red and blue traces). The spectra of the data were shown in Figure B, where respiratory and cardiac cycles were monitored around 0.3 Hz and 1.4 Hz, respectively. After DORK, notable reduction of these two frequency components were observed. Figure C shows the spatial distribution of tSNR before and after DORK. In average the tSNR was improved from 3.9 to 9.9 for real part and from 3.4 to 7.6, respectively. Figure D shows the spatial distribution of the tSNR with/without DORK processing and with/without phase graft. Cyan arrows indicate areas showing more prominent differnce before and after DORK. Regardless of phase graft, DORK improved the tSNR (6.4±2.5 → 7.8±3.6 without phase graft; 49.5±14.8 → 52.9±15.4 with phase graft). The estimated hemodynamic responses at the right visual cortex were shown in Figure E. The most extended visual cortex activity (average between 4 and 6 s after visual stimulation) was found after DORK without phase graft.



DISCUSSION: DORK is an effective approach to monitor and to correct dynamic B_0 disturbance in fMRI experiment using InI. Previously we used phase graft to mitigate the challenge of phase drift over time. DORK can effectively mitigate the same challenge without losing potentially important phase information in phase graft, because only the absolute values of time series were used for InI reconstruction. One limitation of DORK is that it provides no spatial information of the field disturbance. This difficulty can be overcome using an array of field camera [14] at the cost of adding system complexity.

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