IMPLEMENTATION OF NAVIGATOR PHASE CORRECTION IN MULTI-ECHO NON-BALANCED SSFP AT 7T

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Introduction

The use of navigator echoes is an established method for correcting for the global phase variations in the brain caused by respiration induced B0 variations in spoiled gradient echo sequences [1-3]. Usually a single navigator echo at ky=kz=0 is acquired in each TR, and the phase difference as measured relative to a reference phase at the beginning of the sequence is calculated. The imaging echoes within the relevant TR are then multiplied with the TE-corrected complex conjugate phase before reconstruction. Non-balanced Steady-state free precession (nb-SSFP) has been proposed as an alternative sequence for BOLD fMRI at high field strength [4]. Nb-SSFP is attractive because of low rf power deposition and low image distortion, and the possibility of acquiring the T2-weighted S2 signal together with the S1 signal. The use of phase correction also in nb-SSFP could potentially reduce physiological noise and improve the functional SNR. However, as a consequence of the different pathways that contribute to the S1 and S2 signals, the phase might differ significantly between the signals and the standard single echo phase-correction might fail. In this study we investigate the individual S1 and S2 phase variation in a multi-echo nb-SSFP sequence, and evaluate two different methods of phase correction applied to BOLD-fMRI data acquired at 7T.

Materials and methods

A 3D multi-echo non-balanced SSFP was on a Siemens 7 T whole-body Magnetom scanner. The sequence allows acquisition of one or more S1-echoes followed by a single S2-echo within each TR. In addition, two different navigator functionalities were implemented for phase correction. In method A an additional S1 echo at ky=kz=0 was aquired each TR and used to correct both S1 and S2 echoes. In method B the navigator consists of a full TR during which both S1 and S2 echoes were sampled at ky=kz= 0. This navigator scan was acquired every m TR, i.e. interleaved with the imaging scans. Eight subjects were scanned after informed consent was given according to the guidelines of the local ethics committee. To improve SNR and parallel-imaging cabability, a custom-built 7 channel receive surface coil array was inserted into the vendor-provided 8 channel T/R head- coil (Rapid Biomedical). The functional acquisition slab consisted of 24 partitions, axially oriented and tilted towards the coronal plane to align with the calcarine sulcus. In-plane matrix size was 64x64 voxels with an isotropic resolution of 3.0x3.0x3.0 mm^3. Other sequence parameters were FA = 25 deg, BW = 160 Hz/pix, GRAPPA = 4 (left-right), TR = 27 ms; TE1 = 6 ms (S1), TE2 = 11 ms (S1 navigator, method A), TE3 = 18 ms (S1) and TE4 = 24 ms (S2). Volume TR was 6.1 s. The interleave factor m was set to 9, corresponding to the navigator in method B being acquired every 243 ms. The functional paradigm consisted of 5 blocks of 7 resting state volumes (black screen) plus 3 volumes acquired while subjects attended a black/white checkerboard reversing at 7.5 Hz. A rest condition block was acquired at the end, resulting in a total of 57 acquired volumes with a total scan time of around 6 minutes. Before reconstruction, the rawdata was phase-corrected with in-house software written in Matlab (Mathworks) using both method A or B. Offline reconstruction was then performed using the IDEA ICE environment. From each run at total of three datasets were reconstructed: i) no phase correction, ii) phase corrected using method A and iii) phase corrected using method B. Further postprocessing consisted of realignment of functional series and GLM analysis in FSL. Activation maps were thresholded at z = 2.3 and with cluster threshold set to p<0.05.
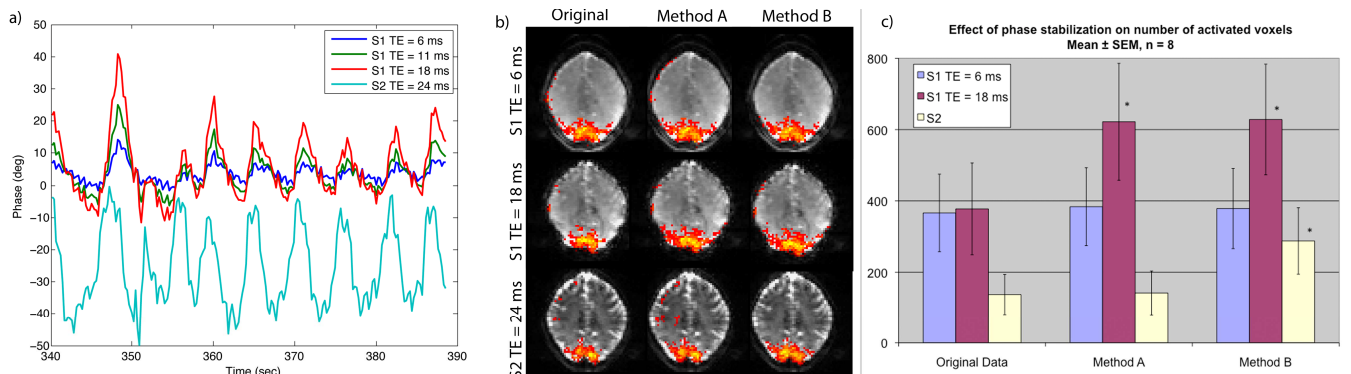
Figure 1. a) Plot of phase variation as function of time. Note how the S2 signal differs from S1. b) Example activation maps in one subject showing significant activation in visual cortex in all three echoes. c) Plot of the number of activated voxels as function of navigator method averaged across all eight subjects. Asterix indicate significant difference (p<0.05, Signed Rank) compared to non-phase corrected data.

Results and discussion

Figure 1a) plots the phase variation in all four sampled echoes over a time period of 50 seconds. The breathing cycles can be clearly observed. Note how the phase of the three different S1 echoes fall on top of each other, while the S2 phase is different. From this it is clear that the phase of S2 cannot be estimated directly from a measurement of the S1 phase. Figure 1b) shows example activations maps calculated from the original (non-phase corrected), and phase corrected data using methods A and B. Average count of activated voxels across all eight subjects are shown in figure 1c). For the short TE S1-echo phase correction has no effect on the number of activated voxels, while the long TE S1-echo shows an increase of about 60 % (p = 0.02, signed rank). This difference in effect is not surprising since the phase accrual from a B0 shift will give a linear phase increase as a function of TE. The S2 signal does not benefit from the phase correction performed by method A, which measures the S1 phase every TR. However, when the actual S2 phase is measured (method B) we see a doubling of the average number of activated voxels (p = 0.02, signed rank). Note that method B performs identical to method A for the long TE S1 signal, despite the phase being measured only every 8th TR as opposed to every TR in method A.

Conclusion

We have implemented navigator phase correction for unbalanced SSFP and demonstrated that S1 and S2 needs to be individually phase corrected. Acquiring the navigators every m TR (every 243 ms in this study) appears to be sufficient to accurately capture the B0 fluctuations induced by the breathing cycle, and allows a more robust phase correction than the more commonly applied sampling at every TR. The T2-weighted S2-signal which has inherently less BOLD sensitivity than T2*-weighted signals can be significantly improved using the proposed phase correction scheme.

References: [1]Hu & Kim MRM 1994, [2] Noll & Schneider, Image Processing 1994; [3] van de Moortele et.al MRM 2002; [4] Barth et.al MRM 2010.