T2- AND T2*-WEIGHTED HIGH-RESOLUTION FMRI AT 7T USING NON-BALANCED SSFP

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Introduction

Non-balanced Steady-state free precession (nb-SSFP) has been proposed as an alternative sequence for T2-weighted BOLD fMRI at high field strength [1]. 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 T2*-weighted S1 signal resembling SE and GE signal characteristics respectively. Our aim was to compare the signal characteristics at the pial surface and within grey matter for both functional contrasts using multi-echo SSFP at high spatial resolution.

Materials and methods

A 3D multi-echo non-balanced SSFP was implemented 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. A spoiler gradient was applied between the S1 and S2 echoes to ensure separation of the signals. To boost sensitivity, a custom-built 7-channel surface coil receive array covering the occipital lobe was inserted into the vendor provided 8-channel T/R head-coil (Rapid Biomedical,Rimpar, Germany). Eight subjects were scanned after informed consent was given according to the guidelines of the local ethics committee. 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 256x256 voxels, and the isotropic voxel size was 0.75 mm. Other sequence parameters were FA = 25 deg, BW = 160 Hz/pix, GRAPPA acceleration factor 4 (left-right), TR = 27.6 ms, TE1 = 7 ms (S1), TE2 = 17 ms (S1) and TE3 = 23.6 ms (S2). Volume TR = 47 s, number of volumes = 35, of which 18 in the rest condition (black screen, fixation point) interleaved with 17 active volumes with black/white checkerboard reversing at 7.5 Hz. Total functional scan time was 27 minutes. In addition, T1-weighted structural reference scans were obtained for each subject (MP-RAGE) together with a retinotopy scan to determine the primary visual cortex V1 [2]. Initial postprocessing steps included realignment of functional series and coregistration with structural reference volume using SPM and voxelwise calculation of the mean signal difference between On and Off volumes. For visualization of activation maps, t-scores were then calculated and thresholded at t = 2.3 after applying an isotropic Gaussian smoothing filter (SD=0.65 voxels). For detailed analysis of signal changes within grey matter and at the pial surface, structural data were segmented using Freesurfer [3,4] and this tissue classification was used to calculate the tissue specific average signal change in V1. Regions affected by flow were masked out based on the phase-data from the first S1 echo.

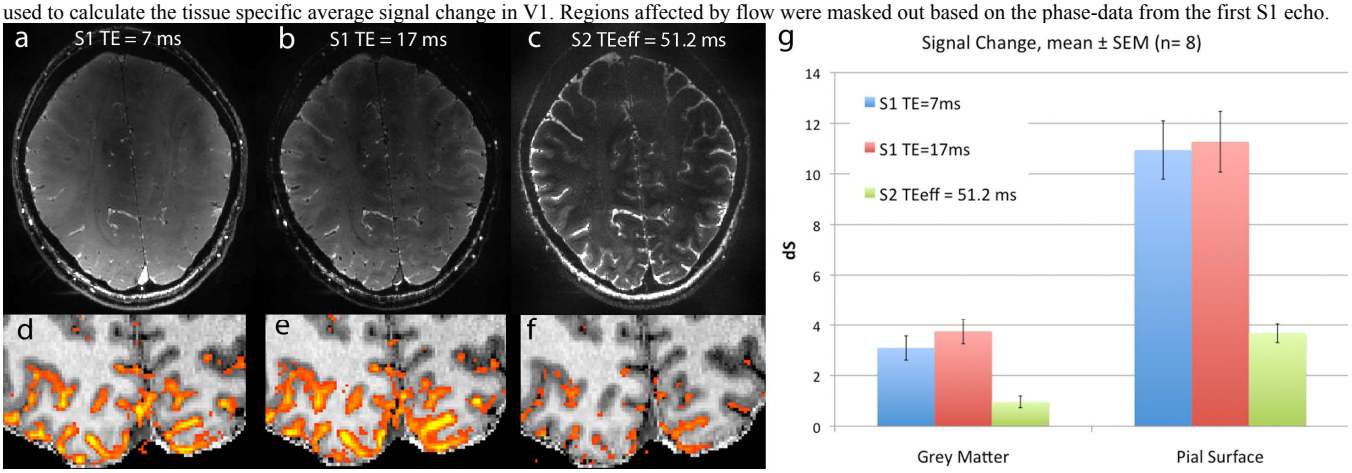

Figure 1. Example mean resting state SSFP images from one subject: a) S1, TE = 7 ms, b) S1 TE = 17 ms, c) S2 with effective TE for the first coherence pathway = 51.2 ms. Zoomed view of the thresholded t-score maps for the first S1 (d), second S1 (e) and S2 (f) echoes overlaid on coregistered MP-RAGE images. Color-range for t-values is 2.3-10. Panel g) shows the average signal changes (mean ± SEM, n= 8) for grey matter and pial surface in the primary visual cortex V1.

Results and discussion

Example mean resting state SSFP images from one subject are shown in figure1a-c . Note the strong reduction in signal intensity from the sagittal sinus when going from the first S1 echo at 7ms (a) to the second S1 echo at 17ms (b), which illustrates the short T2* of venous blood at 7T. In the S2 echo (c), which corresponds to a spin-echo with TE=51.2 ms for the first coherence pathway, no signal from the sagittal sinus can be observed, while CSF with its long T2 is still bright. For better visibility, the intensity in the S2 image has been scaled up by a factor of 3 relative to the two S1 echoes due to the much lower S2 signal intensity. Example thresholded t-score maps are shown overlaid on the coregistered MP-RAGE images in figure 1d-f. Significantly activated voxels are observed in all three echoes, and t-values increase when moving from white matter towards CSF. This is confirmed in figure 1g) where the mean (n= 8) signal change in V1 within grey matter and at the pial surface are plotted for all three echoes. It is somewhat surprising that the first S1 echo at TE = 7 ms has such large signal increase compared to the second S1 at TE= 17 ms despite being much less T2*-weighted. One possible explanation is that at 7 Tesla at such short TE, venous blood is still contributing to the functional contrast [5] as T2/T2* of venous blood at 7T is quite short (~ 7-8ms), but also the contributions of higher pathways could be an explanation. Another surprising result is the high signal change in S2 at the pial surface compared to grey matter, as T2-weighted fMRI is expected to be less sensitive to the contribution from large veins, since the static dephasing surrounding them should no longer contribute to the contrast [6]. Again intravascular blood signal might contribute significantly to the functional contrast, since T2 of blood is expected to depend heavily on oxygenation rate at the field strength of 7 Tesla [7] and consequently a change in blood oxygenation would lead to a much higher signal change compared to grey matter due to the higher blood volume at the pial surface.

Conclusion

We have for the first time demonstrated the capability of multi-echo nb-SSFP for high-resolution simultaneous T2-weighted and T2*-weighted BOLD-fMRI at 7T, indicating that nb-SSFP may provide an attractive distortion-free alternative to the more commonly used GRE or SE-EPI. In case that S1 and S2 signals closely mimick GRE and SE characteristics a clear benefit of SE for enhancing specificity in fMRI at high fields is questionable, also in view of the practical limitations usually encountered due to the high power deposition (SAR) in pure SE sequences..

References: [1] Barth et.al MRM 2010; [2] Engel et al., Cereb. Cortex 1997; [3] Fischl et al. Neuroimage 1999; [4] Koopmans et.al HBM 2010;[5] Poser & Norris Neuroimage 2009; [6] Yacoub et.al MRM 2003; [7] Uludag et.al Neuroimage 2009.