A 3D-PRESTO-SENSE sequence with UNFOLD and partial fourier encoding for fast susceptibility-weighted MRI

M. Ries[1], C. Modolo[1], C. T. Moonen[1]
[1]IMF, CNRS/Universite Victor Segalen Bordeaux 2, Bordeaux, Aquitaine, France

Introduction
MRI-sequences for functional-BOLD imaging and bolus tracking require a high temporal resolution while maintaining large brain coverage.
Although multislice, single-shot EPI are widely used in this role, often in conjunction with parallel imaging techniques like SENSE[1], the acquisition scheme of the 3D-PRESTO[2] sequence offers the advantage of maintaining long effective echo-times, while exploiting the maximum available imaging time.
In combination with SENSE and partial fourier acquisition schemes, PRESTO sequences can reach imaging times of 0.5s per volume and maintain full head coverage (isotropic resolution of 4mm)[3]. The aim of the presented feasibility study is to extend this idea by combining the UNFOLD[4] method, the SENSE method and a partial k-space sampling scheme with a 3D-PRESTO sequence an evaluate it's usefulness in an simple event related fMRI-experiment.

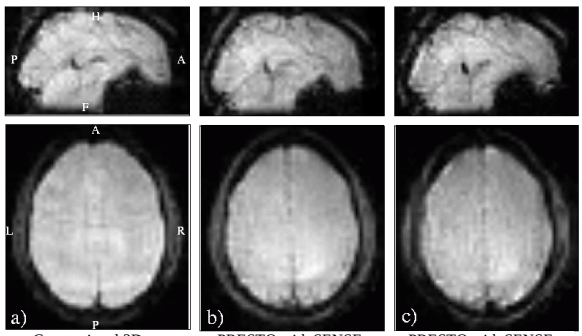
Material and methods
All Experiments were performed with a six channel headcoil on a Philips 1.5T Intera system with explorer gradients (Gmax=23mT/m, slew rate S=120T/ms). All sequences used a FOV of 256x205x120mm^3 and an imaging matrix of 64x52x30 resulting in an isotropic resolution of 4mm. For excitation a water-selective 1-2-1 binomial RF-pulse with a flip angle of 11° was used. For the 3D encoding the left-right direction was used, for the EPI-readout the anterior-posterior direction (BW/pixel: 3.5KHz) and for the fast phase encoding (EPI-blip) direction the head-foot direction. A navigator-echo prior to each readout train was employed to achieve a higher temporal stability of the 64 acquired volumes. Compared were the following three sequences:
1. Conventional 3D-PRESTO with: TE_{eff}=41ms, TR=27ms, EPI readout train of 31 lines and a complete acquisition time per 3D-volume of 1.6s.
2. PRESTO with a SENSE-factor of 2 (in 3D enc. dir) and UNFOLD-factor 2 (in EPI-blip dir) with: TE_{eff}=30ms, TR=18ms, EPI readout train of 15 lines and a complete acquisition time per 3D-volume of 540ms.
3. PRESTO with a SENSE-factor 2 (in 3D enc. dir) and UNFOLD-factor 2 (in EPI-blip dir) and 70% partial-k space sampling (in 3D enc. dir): TE_{eff}=30ms, TR=18ms, EPI readout train of 15 lines and a complete acquisition time per 3D-volume of 350ms.

FMRI-experiment: For the fMRI-experiment a visual flickering-checkerboard stimulus was used with a jittered interstimulus interval (ISI) and a mean ISI of 2.8s, resulting in a total paradigm duration of 4.6min. The fMRI experiment was performed with the third PRESTO sequence (SENSE /UNFOLD /partial-k space) and with a standard multislice-EPI (TE=45ms, TR=2.8s, BW/pixel=2.1kHz, 100 volumes acquired) of a similar matrix size and resolution for comparison.
Image Processing: All PRESTO images were reconstructed off-line using the standard reconstruction schemes for SENSE and UNFOLD and the Cuppen method for full k-space restoration for the partial-k space sampled data. For the UNFOLD reconstruction of the fMRI-experiment a sliding window technique with a window size of 64 images was used.

Results:
Figure 1 shows a sagittal and transversal slice of the 3D-PRESTO (a), 3D-PRESTO /SENSE /UNFOLD (b), 3D-PRESTO /SENSE /UNFOLD /partial k-space (.c) sequence. Despite the inevitable artifacts introduced by partial k-space sampling (c), the latter shows a sufficient SNR and an acceptable level of distortions/ghosting. Note the improved resolution in HF-direction of the UNFOLD sequence (b), caused by the shortened EPI-train. The fMRI experiment displayed in figure 2 evidenced sufficient T_2^*-weighting to reliably detect the visual activation. However, the problem of motion artifacts on the UNFOLD reconstruction has to be carefully addressed in the future.

Discussion/Conclusion:
3D-imaging methods like 3D-PRESTO for fast susceptibility-weighted MRI offer the flexibility to use a combination of multiple fast imaging techniques in more than one direction in order to shorten acquisition trains and to accelerate the total data acquisition without significant loss of T_2^*-weighting. In the presented feasibility study, the combination of SENSE, UNFOLD and partial k-space sampling with the PRESTO sequence offers the possibility of sampling susceptibility weighted whole brain volumes on a clinical 1.5T system within 350ms.
Although the principal temporal resolution limits of the UNFOLD method apply[4], the high temporal resolution suggests the proposed sequence as an interesting candidate for bolus-tracking perfusion and event related fMRI studies.

References:
[1] Prussmann et al. MRM 1999;42:952-962
[2] Liu et al. MRM 1993;30:764-768
[3] Klarhoefer et al. MRM 2003;50:830-838
[4] Madore et al. MRM 1999;42:813-828



Conventional 3D-PRESTO | PRESTO with SENSE-factor 2 (LR) and UNFOLD factor 2 (SI) | PRESTO with SENSE-factor 2 (LR) and UNFOLD factor 2 (SI) and half k-space sampling (LR)

Figure 1

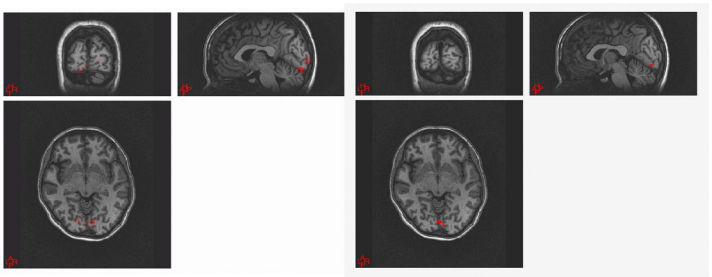


Figure 2: Results of the visual fMRI-Paradigme of the EPI-experiment (left) and the PRESTO/SENSE/UNFOLD/partial k-space experiment (right). Displayed in red the thresholded (p=0.05, corrected for multiple comparison) t-test result for the event related flicker stimulus.