PACEUP-3DEPI: A highly Accelerated 3D-EPI Sequence for fMRI at 7T

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Introduction: Echo Planar Imaging (EPI) has been the main work-horse of functional magnetic resonance imaging (fMRI) because of its high sampling rate. Due to increased signal strength at high magnetic fields and to reduce susceptibility induced artifacts, there is both an opportunity and a need to acquire higher spatial resolutions. Such needs introduce constraints to the minimum TR achievable when covering the whole brain. This has fuelled the interest of z-acceleration methodologies such as Multiplexed echo planar imaging (1) or segmented 3DEPI (2). In this work we present a new sequence, PACEUP-3DEPI (ksPACE acqUisition Parallelized 3D-EPI) that allows a further acceleration in the z-encoding direction compared to the conventional 3D-EPI.

Methods: A segmented 3D-EPI sequence was modified to create the PACEUP-3DEPI sequence (Fig. 1) which encodes 2 kspace planes per rf excitation, instead of a single kspace plane encoded in 3D-EPI. In PACEUP-3DEPI, the z-partition encoding gradient is blipped with alternating polarity in between every k-space line during the EPI echo train while the conventional phase encoding blips are only performed every two readouts. In this manner, the positive readout gradient k-space lines fall in the odd z-partitions and negative readout gradient k-space lines in the even z-partitions, effectively moving the Nyquist ghost from the phase encoding to the slice encoding direction.

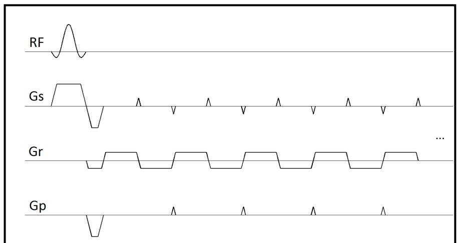

Figure 1 PACEUP-3DEPI sequence

Experiments were performed on a 7T system (Siemens, Germany) using an 8-channel coil (Rapid Biomedical, Germany). 3 subjects were scanned in accordance with the procedures approved by the local ethics committee.

Image quality was compared between different z-accelerations (Grappa, partial Fourier and multi-kspace), The remaining sequence parameters were: TR/TE 76/30ms; FA 9^o; 1.5mm isotropic resolution; matrix size 128x128x112; readout bandwidth (rBW) 2056 Hz/Pixel, iPAT=2 and PF 6/8 were used on the phase encoding direction and frequency selective fat saturation was used. Given the RF coil setup (8Ch coil allows acceleration on only the L-R and A-P direction), sagittal images were acquired with the phase encoding direction along the anterior-posterior axis.

The temporal SNR and resting state network detection of the PACEUP-3DEPI data was evaluated in resting state functional data and compared to matched 2D-EPI and 3D-EPI data. Protocols used were as follows: $TR_{segment}$/TE 60/28ms, FA = 17deg, FOV 192x192mm, rBW 2264Hz/Pixel, matrix size 96x96x40, iPAT 2x1, PF_{phase} 7/8, PF_{slice} 6/8 resulting in TR_{volume} of 1.8s for segmented 3D EPI and 0.9s for PACEUP-3DEPI. The same resolution, BW and echo time, and volume coverage were used for the 2D EPI which had a TR_{volume} of 2.4s (limited by the number of slices needed to encode the same volume at the same resolution). The resting state data was acquired using axial slices with the PE direction on the A-P direction. Total scan time was kept constant between the three sequences. Resting state data were processed in fsl (www.fmrib.ox.ac.uk) using MELODIC to unveil the resting state networks.

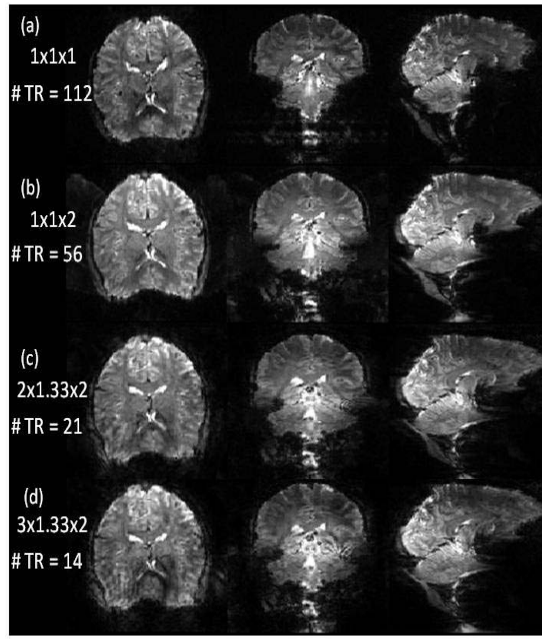

Figure 2 shows in the different columns 3 orthogonal slices from one volume obtained using PACEUP-3DEPI with different slice accelerations ranging from 1 to 8. On the left the achieved slice acceleration used is presented as (GRAPPA)x(PF)x(N) where GRAPPA is the grappa acceleration factor used in the z direction, PF is the partial Fourier acceleration and N is number of kspace planes encoded per rf excitation for 3D EPI. Total number of $TR_{segment}$ needed for volume acquisition is also indicated.

Results and discussion: PACEUP-3DEPI provides a twofold acceleration which can be combined with other conventional approaches to achieve an acceleration up to 8-fold in the slice encoding direction (Fig. 2). The only visible differences are the shift of the Nyquist ghost from the phase encode to the slice encode direction, and the increased distortions in the phase encoding direction reflecting the increased EPI train length (see fig. 2(a) and fig. 2(b)). Ability to achieve 8x acceleration in the slice encode direction with an 8-channel coil is demonstrated in Fig. 2d. Fig. 3 shows that an increased number of resting state networks were identified in the 0.9s PACEUP-3DEPI data, notably the salience and auditory networks which were absent in the 2D-EPI and 3D-EPI results. In addition, the larger number of time points improved the spontaneous neural fluctuations' Z-scores by as much as 70% compared to the equivalent 2D-EPI and 45% compared to the 3D-EPI. One of the limiting aspects in terms of temporal SNR of 3D-EPI is the number of segments used to achieve the volume coverage (3). PACEUP-3DEPI uses a significantly reduced number of segments to acquire a volume, as well as a lower TR_{volume}, increasing BOLD sensitivity significantly. In the current implementation, 2 kspace planes per excitation were explored but it is possible to envisage higher number of kspace planes if higher temporal and lower spatial resolutions are desired. The technique would benefit from an increased number of receiver coils that would offer flexibility in the orientation in which the encoding is done. With a 32 channel coil it could be envisaged to acquire the resting state data with an effective TR_{volume} of 0.3s, without the need to use computationally intensive iterative methods. This reduction can be used to shorten scan times, to acquire higher spatial resolutions, to investigate temporal dynamics of the fMRI response, or to better characterize physiological noise.

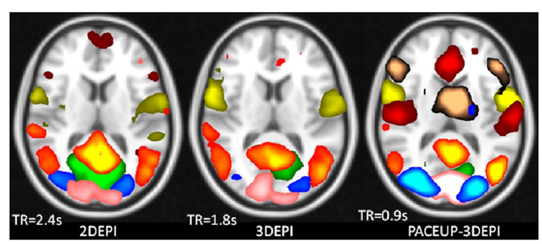

Figure 3 comparison of resting state networks at different TR

Conclusions: An implementation of 3D-EPI which acquires two k-space planes in one shot, PACEUP-3DEPI, yields increased temporal resolution and reduced physiological noise sentivity compared to 3D-EPI. The sampling of k-space lines in alternate planes increases image quality by shifting the Nyquist ghost from the phase-encoding to the slice-selection direction. A higher number of resting state networks was detected in PACEUP-3DEPI data compared to matched 2D and 3D-EPI.

References: 1. Feinberg et al PLoS ONE, 2010; 2. Poser et al, Neuroimage, 2010 ; 3. van der Zwaag et al MRM, 2011

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