PEAK-EPI: Feasibility and benefits of k-t-undersampled EPI acquisition and PEAK-GRAPPA reconstruction in fMRI

Rebecca Ramb[1], Pierre Levan[1], and Jürgen Hennig[1]
[1]*Department of Radiology, Medical Physics, University Medical Center, Freiburg, Germany*

Purpose: Echo planar imaging (EPI)[1,2] still is the most commonly applied technique in brain imaging (fMRI, perfusion, diffusion) achieving brain coverage to the greatest possible extent at reasonable - and in trade-off with - spatial and temporal resolution. However, long EPI readout times lead to artifacts as well as increased TR in multislice acquisitions especially at high spatial resolutions. Parallel imaging approaches such as SENSE[3] or GRAPPA[4] can reduce echo train length and/or scan time, e.g.[5,6,7], but also result in severe losses in signal-to-noise-ratio (SNR) at even moderate acceleration factors[6]. To yet seize the benefits of the shortened echo train - which then facilitates an increase of other resolution parameters - while maintaining sufficient SNR and data fidelity, we present the feasibility of PEAK-EPI, i.e. permuted interleaved EPI acquisition together with PEAK-GRAPPA[8] reconstruction, in task-related fMRI. PEAK-EPI achieves high spatial resolution (2 *mm* at 3T) and whole brain coverage (60-63 slices), whereas only partial brain coverage (43 slices) can be attained at the same TR with 5/8-Partial Fourier EPI - omitting the first echoes.

Methods: With an in-house developed (PEAK-)EPI sequence, three task-related fMRI datasets (visuo-motor stimulus consisting of a flickering checkerboard with simultaneous sequential finger tapping on the right hand, alternating blocks 40 *s* on/off) were acquired in two healthy volunteers on a 3T PRISMA (Siemens, Erlangen, Germany) equipped with a 16-channel head coil array. The three acquisition procedures at an effective TE of 30 *ms* consisted of: 1. EPI (5/8-Partial Fourier, fully-sampled phases), 2. inPEAK-EPI at reduction factor R = 5 with 20 inplace acquired ACS lines (net reduction factor of 2.78), 3. exPEAK-EPI with extra acquired ACS data (20 phase encoding lines, 20 repetitions) and actual scan with R = 5. The spatial resolution in all measurements was 2.0×2.0×2.0 mm^3 (matrix size 100×100) with a temporal resolution of TR = 3.6 *s*. Whereas the maximum number of slices within the given spatial/temporal resolution was restricted to 43 slices in the EPI acquisition, an increase to 60 slices for inPEAK-EPI and 63 slices for exPEAK-EPI was achieved. With exPEAK-EPI, reconstruction was performed in two iterations: 1. reconstruction of a full dataset to obtain pseudo-inplace ACS data, 2. reconstruction with kernel weights dynamically calibrated for each time frame. In the undersampled scenarios, additional conventional GRAPPA reconstruction was performed for comparison.

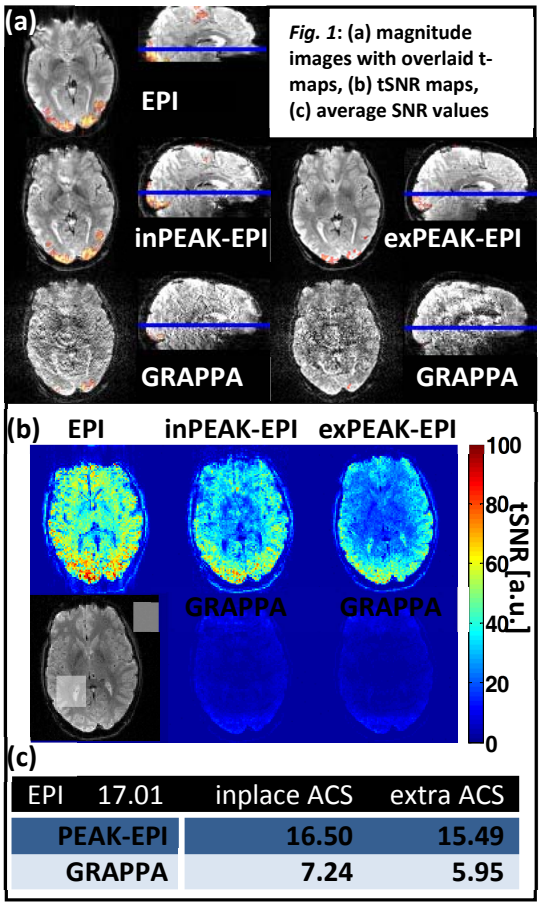

***Fig. 1*: (a) magnitude images with overlaid t-maps, (b) tSNR maps, (c) average SNR values**

Results: *Fig.1(a)* depicts single slice magnitude images of one volunteer with overlaid activation maps (general linear model, p<0.05 corrected). For inPEAK-EPI, the activation is comparable to the reference EPI acquisition, whereas the activation is present, although attenuated, for exPEAK-EPI. In the GRAPPA reconstructions, only very weak activations could be derived due to a high amount of noise. Both tSNR maps *(Fig.1(b))* and SNR values *(Fig.1(c))* confirm a much better SNR and data fidelity performance in the PEAK-EPI scenarios compared with GRAPPA reconstruction; and only slightly decreased values compared with the EPI reference. SNR values were estimated from the signal and noise regions (gray boxes) and averaged over all time frames. *Fig.2* displays magnitude images of multiple slices together with activation maps of a further volunteer and demonstrates the improved brain coverage of PEAK-EPI. The activation maps of inPEAK-EPI are again in good agreement with the EPI measurement and previously made observations could further be reproduced. Additionally, PEAK-EPI acquisitions yield reduced distortions in orbitofrontal regions (red box).

Discussion and Conclusion: PEAK-EPI allows for echo train length reduction and faster k-space traversal while maintaining high SNR and tSNR. The somewhat reduced tSNR of exPEAK-EPI could be improved by further optimization of the dynamic kernel adaptation procedure. The performed fMRI experiments confirm the feasibility of PEAK-EPI in deriving task-related activation maps at a reduction factor where non-time-resolved parallel imaging is no longer applicable. With the reduced readout after each excitation, improved brain coverage at fixed spatial resolution within the same TR was realized. The achieved gains could also be translated into higher spatial or temporal resolution or - with respect to applications like DSC-MRI, DCE-MRI or arterial spin labeling - additionally into a shorter TE. In fMRI, PEAK-EPI provides high spatial resolution (2 *mm* at 3T) while mitigating distortions effects due to the shortened acquisition times per slice. PEAK-EPI also has the potential to alleviate these issues at higher field strength, e.g. at 7T, where they become even more relevant[9]. Moreover, PEAK-EPI can be readily combined with multiband[10,11] excitation to further increase the data acquisition efficiency in scans with high temporal and spatial resolution.

References: [1]Mansfield et al. J. Phys. 1977 [2]Ordidge et al. BJR 1981 [3]Pruessmann et al. MRM 1999 [4]Griswold et al. MRM 2002 [5]Griswold et al. MRM 1999 [6]Preibitsch et al. NI 2003 [7]Newbould et al. ISMRM 2006 [8]Jung et al. MRM 2008 [9]De Martino et al. NI 2011 [10]Larkman et al. JMRI 2001 [11]Moeller et al. MRM 2009

Acknowledgements: We thank Ralf Deichmann for sharing his FLASH-EPI sequence which served as a basis for the sequence development and the German Research Foundation (DFG), grant JU2876/4-1.

***Fig. 2:* Magnitude images and activation maps of the three fMRI experiments.**