High resolution fMRI using Short Axis readout propeller EPI (SAP-EPI)

A. Nordell[1], S. Holdsworth[2], R. Newbould[2], R. Bammer[2], and S. Skare[2]

[1]Hospital physics, Karolinska University Hospital, Stockholm, Sweden, [2]Radiology, Stanford University, Palo Alto, CA, United States

INTRODUCTION: In fMRI, the BOLD response is dependent on the resolution employed by the imaging sequence, the point spread function (PSF) of the haemodynamic response and the sensitivity of the experiment [2]. Using a standard 64x64 single shot EPI sequence, the resolution is of the same size as the haemodynamic PSF, which significantly adds to the uncertainty in the spatial extent of the BOLD response. In this work we have investigated the use of a GRE version of our Short-Axis Readout Propeller EPI (SAP-EPI) [1] for fMRI. With this sampling strategy, our aim is to increase the resolution of the BOLD response by increasing both the sensitivity and spatial resolution of the acquired images.

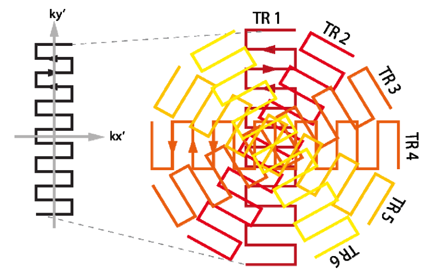

Fig. 1 The SAP-EPI trajectory is shown. A full k-space consists of 6 excitations at different angles, with all trajectories crossing the k-space center. In order to reduce distortions, the readout direction is along the short axis of each blade.

METHODS: Gradient Echo SAP-EPI (GE-SAP-EPI) is a T2*-weighted EPI sequence, where each excitation is followed by an EPI trajectory or 'blade' which is narrow in the readout direction and long in the phase encoding direction. This blade is rotated around the center of k-space (Fig. 1). The readout length is kept short in order to decrease the echo spacing, which is directly proportional to image distortion.

The aim of the experiment was to investigate the reproducibility of the BOLD response using a simple fMRI stimulus. Three subjects were scanned at 5 sessions (each lasted approx. 30 minutes) within one week. In each session the SAP-EPI was scanned twice (first and last). The fMRI experiment consisted of a block design over 240s with alternating 20s rest and 20s activation periods. The stimulus was simultaneous left-handed finger tapping together with a visual black&white checkerboard flickering at 4 Hz. All fMRI volumes were 3D realigned (SPM2) and the time course was detrended prior to analysis. Correlation analysis was performed as described in [4].

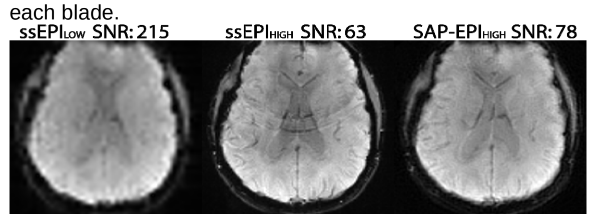

Fig. 2 A single slice, single volume from the three sequences tested. The ssEPI image shows the largest SNR in accordance with theory. SAP-EPI$_{HIGH}$ has a higher SNR than ssEPI$_{HIGH}$.

All scans were performed on a 3T GE Excite (Milwaukee, WI) scanner with the scan parameters: TR/TE/FA = 1000ms/30ms/61°, FOV/sl.th./#slices= 26cm/5mm/17. Each volume of the GE-SAP-EPI acquisition was reconstructed from 6 propeller blades at angles 0, 30, 60, 90, 120, and 150° (Fig. 1), and gridded onto two target grids of $N_x \times N_y$=171×171 (called "SAP-EPI$_{HIGH}$") and $N_x \times N_y$=64×64 ("SAP-EPI$_{LOW}$"), respectively. Since all k-space trajectories traverse the center of k-space, reconstruction becomes flexible with respect to low/high spatial and temporal resolution. This approach allows one to reconstruct a low-resolution image every TR and a full high-resolution every 6 TR or every TR using a sliding window approach. A single-volume spin echo SAP-EPI using the same blade angles was scanned prior to each fMRI-scan and was used as a calibration scan for Nyquist ghost correction, GRAPPA weights determination and distortion field estimation [3].

For comparison, two additional fMRI series using ssEPI were acquired; first a standard ssEPI with 64×64 resolution ("ssEPI$_{LOW}$") followed by a 162×160 scan with GRAPPA R=3 ("ssEPI$_{HIGH}$"). Data from both ssEPI scans were reconstructed using a temporal sliding window of 6 TRs to match the gridded volumes of the (high-resolution ??) SAP-EPI with respect to SNR. Following this, a second SAP-EPI scan was performed to rule out subject fatigue or varied level of attention that may bias the comparison.

RESULTS: Figure 2 shows a single slice from the three scans; ssEPI$_{HIGH}$, ssEPI$_{LOW}$ and GE-SAP-EPI, reconstructed with the same frame rate. Figure 3 shows zoomed single slice correlation maps of the motor cortex from one subject scanned in 5 sessions. Note that SAP-EPI was scanned twice in each session. The rightmost column shows the mean correlation from all sessions. Note that ssEPI$_{LOW}$ and SAP-EPI$_{LOW}$ show similar high sensitivity with large areas of activations. Furthermore, SAP-EPI$_{HIGH}$ outperforms ssEPI$_{HIGH}$, showing similar spatial extent of the BOLD response, but with a larger degree of reproducibility.

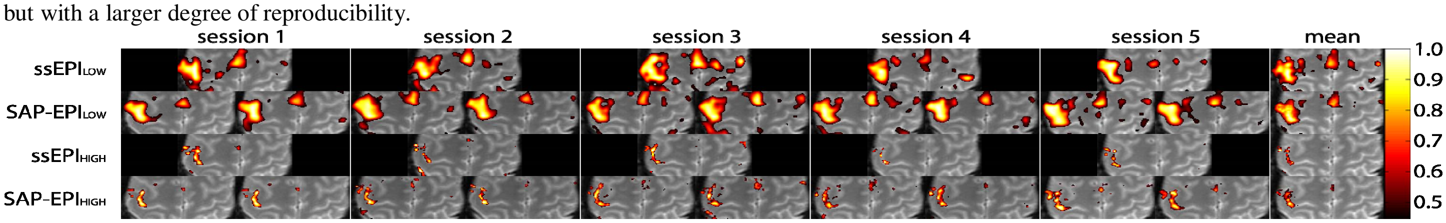

Fig. 3 A single slice through the motor cortex from 5 sessions is shown. Do note that the anatomical underlay is constructed from the SE-SAP-EPI calibration scan. The activation was thresholded at a correlation coefficient of 0.45. The colorbar to the far right corresponds to the correlation coefficient.

DISCUSSION: Results show that the GE-SAP-EPI with a finely tuned reconstruction is well suited for high resolution fMRI. Moreover it shows good reproducibility between sessions and a high spatial definition of the BOLD response. With the proposed reconstruction of the GE-SAP-EPI with 6 blades to reconstruct one dynamic frame (i.e. similar to temporal smoothing or sliding window reconstruction), the sequence is currently geared towards fMRI block design. Compared to ssEPI the temporal footprint is worse which needs to be considered especially when moving to event-related paradigms. Since all blades cross the center of k-space, there is a degree of freedom in selecting the spatial and temporal resolution (e.g. a 64x64 image can be reconstructed at the highest possible frame rate to provide a good prior). High resolution fMRI reconstructed at several resolutions may be a new interesting tool in clinical fMRI applications such as neurosurgical planning. The spatial blurring from the low resolution scans was marked compared to high resolution scans. Particularly for surgical planning extra caution should therefore be exercised.

REFERENCES: [1] Skare S. et al. MRM 2006;55:1298-1307, [2] Norris et al., [3] Chang H, Fitzpatrick J. IEEE Trans Med 1992;11:319–329, [4] Lai et al. MRM 1995 745-754