Variable Flip Angle 3D-GRASE for Increased Spatial Coverage and Improved Point Spread Function in High Resolution fMRI at 7T

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Target Audience. MR physicists and researchers interested in ultra-high field and high-resolution fMRI

Purpose. In this study we investigated, how variable flip angle acquisition schemes in Inner-Volume 3D Gradient-and-Spin-Echo (3D-GRASE [1,2]) sequences can be used to increase spatial coverage and reduce point spread along the partition direction.

Introduction. 3D-GRASE sequences have a T2 weighted contrast, which is preferable over T2* weighted EPI in high resolution fMRI [3], but have a limited field of view (FoV) to minimize T2* weighting and point spread along the second phase encoding direction (partition direction). Parallel imaging techniques such as GRAPPA can be used to increase the FoV in both phase encoding directions, however, coil sensitivities need to be sufficiently distinct on the small FoV to minimize g-factor related degradation of the signal-to-noise ratio (SNR).

A tailored variable flip angle train, such as typically employed in long spin-echo train sequences (RARE/TSE/FSE) [4,5], allows for flexible control of the resulting signal envelop. The echo train can be sustained because a variable amount of stimulated echoes decays with T1 instead of T2. Simultaneously, more stimulated echo contrast is introduced, which has previously been shown to result in equally high BOLD-contrast[6].

Methods & Results. Phase graph theory was used to calculate signal evolution in 3D-GRASE echo trains using MATLAB. Only the multi-echo spin-echo part of the signal was considered. Variable flip angle schemes were designed based on a reference acquisition employing perfect 180° refocusing flip angles, such that the signal evolved in a slower exponential decay. The extended echo train was used to a) increase the coverage (VFA Slice), and b) to obviate partial Fourier acquisition (VFA FF), see Fig. 1.

All Experiments were performed on a 7 Tesla Siemens Magnetom scanner with a body gradient coil (70 mT/m, 200 mT/m/s) and a head radio frequency coil array (32 channel Rx; quadrature Tx). Four acquisition schemes were tested: 1) Conventional *180°* refocusing; 2) Conventional 180° refocusing with GRAPPA *R=2* doubling the field of view in-plane; 3) *VFA Slice* with 20 instead of 12 slices; 4) *VFA FF* with full acquisition instead of partial Fourier 5/8 (black lines in Fig. 1). Other imaging parameters: TR/TE, 2000 ms/30-31 ms; in-plane matrix size, 128x32; resolution, $(1.1\text{mm})^3$; echo spacing, 0.82 ms. Phase encoding in both directions was turned off to obtain the point-spread function of each acquisition (2-parameter least-squares fit of a Lorentzian function to normalized signal intensities, Fig. 2). For functional experiments a visual stimulation (8 Hz flickering checkerboards) block design with 14 blocks of 10 s stimulation and 12 s rest was chosen. Two healthy volunteers were scanned in agreement with local ethical approval. Temporal signal to noise (tSNR) maps were calculated from motion-corrected and temporally high-pass filtered time series (160 time points; Fig. 3). A GLM was used to create functional activation maps (Fig. 4). All fMRI analysis was performed using BrainVoyager QX 2.8.

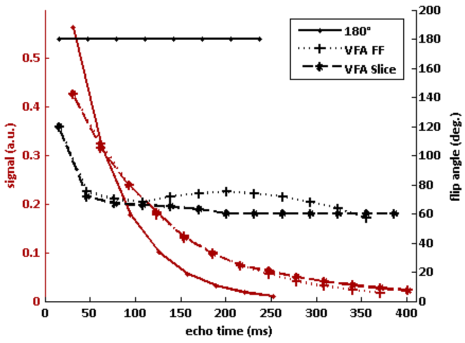

Fig.1: Simulated signal evolution (red, left axis) and flip angle trains (black, right axis) for conventional (180°) and VFA acquisitions (see Methods for details). These pulse trains were also used in the empirical experiments.

Discussion. This study shows the applicability of variable flip angle acquisitions in 3D-GRASE sequences for high-resolution fMRI at ultra-high field. The framework can be readily utilized with different imaging parameters, e.g. sub-millimeter resolution. This yields the possibility to balance blurring, SNR, and coverage more freely than with conventional 180° refocusing. In this experiment, the number of slices was increased from 12 to 20 while maintaining the same point spread properties and tSNR as obtained with conventional 180° refocusing (Fig. 2). The tSNR is preserved because the increased imaging volume counterbalances the signal reduction from low flip angle refocusing (Fig. 3). Expanding the FoV in phase-encoding direction in combination with variable flip angles is likely to yield better results than using GRAPPA, which was impeded by insufficient receive coil sensitivity differences. The difference in blurring between the conventional and the VFA FF acquisition was lower than predicted from the simulation, partly because the conventional method has less blurring in imperfect B1 transmit field.

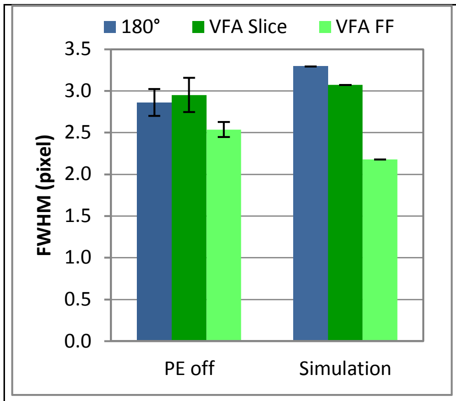

Fig. 2: Point spread of conventional, VFA Slice, and VFA FF acquisition. Full width half maximum fitted to non-phase encoded data (PE off) and to simulation.

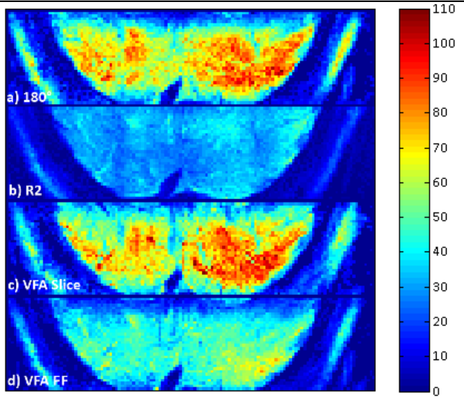

Fig. 3: temporal signal-to-noise maps of (a) conventional 180° refocusing, (b) GRAPPA R=2 (cropped), (c) VFA Slice, and (d) VFA FF acquisition.

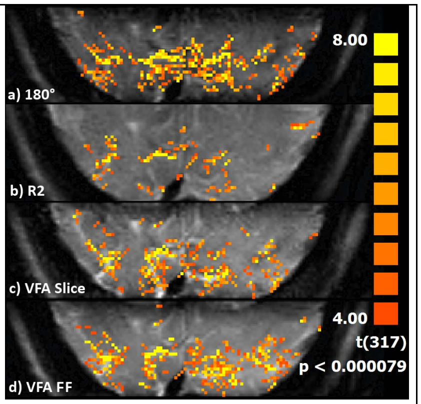

Fig. 4: t-Value map of visual activation maps overlaid on single slices of averaged fMRI data. Same order as in Fig. 3

References. [1] Feinberg DA Radiology 1985;156:743. [2]Feinberg DA Proc. ISMRM 16; 2008. [3] De Martino, Zimmermann, PloS 2013;8:3. [4] Hennig J, Scheffler K, Mag. Res. Med. 2000;44:983. [5] Busse RF Mag. Res. Med. 2006;55:1030. [6] Goerke U, Mag. Res. Med. 58:754(2007)