Optimized fMRI of Hand-Squeezing at 3T

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Introduction: BOLD fMRI using EPI at high spatial resolution is challenging unless one limits field of view (FOV), and uses long TRs (thus reducing the number of timepoints acquired in a given period of time) and/or long TE, thus suffering increased distortions and signal dropout due to $T2^*$. We developed an "optimized" EPI protocol for high-spatial resolution, whole-brain coverage, BOLD fMRI, using GRAPPA. We have validated our protocol against fMRI with a "standard" non-GRAPPA EPI and have measured motor cortex activation versus force of squeezing at 3T (previously studied at 1.5T, [1]), using a squeezing motor task that has been useful in clinical brain mapping of human motor deficits. We have performed GRAPPA-fMRI experiments using a Siemens 12-channel TIM array and a novel 32-channel surface phased array [2]. The fMRI data are of higher quality and the area of activation is larger using the latter. The SNR gains of the 32-channel phased array are up to 3.5 times (typically 2.5-fold) in the cortex and 1.4-fold in the corpus callosum when compared to the commercial eight-channel domed head coil. Compared to the CP head coil, the 32-channel array showed an SNR increase of as much as six-fold (in the distal cortex) and 2.4-fold in the center of the head.

Materials and Methods: BOLD fMRI mapping of brain activation using a motor paradigm: We monitor the changing levels of force during compression (squeezing), and compare levels of compression force with features of brain activation. Our block-design paradigm consists of three alternate action (A) and resting (R) epochs, 30 sec each. During the action epoch the subject compresses and releases continuously at 1Hz rate exercise gel balls at 15%, 45% and 60% of own maximum force. Maximum force is measured using a dynamometer, and the subjects are instructed to squeeze the dynamometer and the gel balls until they consistently perform to the required squeeze level without having to look at the gauge. The percent levels compensate for performance confounds by constraining between-subjects performance to be approximately the same, and the 60% top level allows all to perform the task even if exerting only a limited force. Subject training typically necessitates 10-15min before scanning. BOLD fMRI was performed using an "optimized" gradient-echo EPI protocol using parallel-imaging (GRAPPA) acquisition/reconstruction on healthy volunteers (23-36 years of age, N=12) on a Siemens Trio 3T. Acquisition parameters were: TR/TE=3000/31.1 ms, GRAPPA factor=3, voxel size (1.6mm)2×3.0 mm, 128×128 acquisition matrix/200mmx200mm FOV, 48 slices (5% skip) covering the entire brain with a tilted axial orientation, 85 PE reference lines for GRAPPA calibration. The task was repeated with a "standard" EPI sequence (TR/TE = 1500/30 ms, no GRAPPA, voxel size (3.1mm)2×5.0mm) for comparison. All images were registered to a standard template and processed with SPM2 ($p<0.05$ corrected for multiple comparisons). Volunteers were able to complete each level without fatigue. Arms are kept extended at the sides of the subject and extra padding is used to minimize elbow flexion and further reflexive motion, and to minimize head translational and rotational motion. Typically, translational (head) motion is well lesser than 1mm.

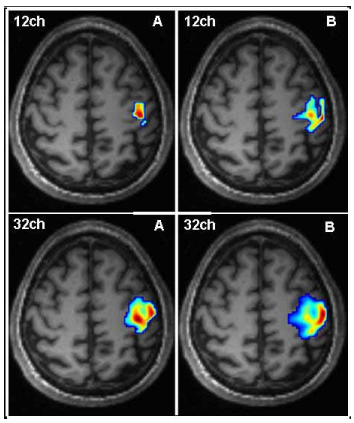

Figure 3: Motor FMRI activation images. A = 15%, B = 60% of maximum force. %BOLD signal change (color) is scaled to the same upper value in both images. Both activation area and %BOLD amplitude increased with force of squeezing; B > A.

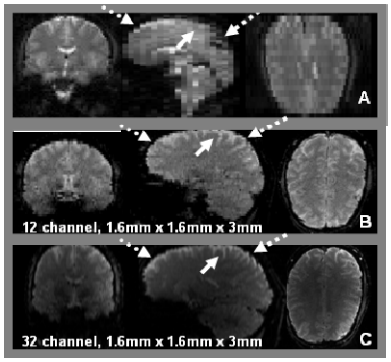

Fig. 1

Figure 1: Standard EPI images, acquired with no Grappa (panel A) and improved EPI images (panel B, C) using GRAPPA and 32 channel phased array (C). Less signal dropout (dotted arrows) and improved cortical resolution (solid arrows).

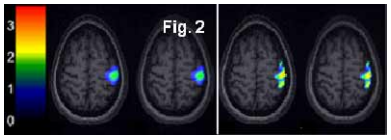

Figure 2: Typical %BOLD activation images of the non-GRAPPA EPI (left) versus GRAPPA-EPI fMRI protocol (right). GRAPPA fMRI shows higher %BOLD amplitudes and improved cortical specificity.

Results: (A) Our "optimized" fMRI has less ghosting and fewer distortions than the standard protocol, high image SNR , approximately 50% higher % BOLD signal changes and improved cortical specificity of activation compared to the "standard" fMRI (Fig. 1, 2). Typical image-SNR figures are 80 for the low-resolution non-GRAPPA EPI and 120-130 for the high-resolution GRAPPA EPI protocol. **(B)** Validation: Activation was seen in the same brain areas and followed the same pattern using both the GRAPPA and non-GRAPPA EPI protocols, but measured % BOLD signal changes were consistently higher using the high-resolution GRAPPA protocol (Figure 2, 3), as expected from partial-voluming effects and from the combination of smaller voxels and high image-SNR where the asymptotic limit of timeseries-SNR has not yet been reached [3]. **(C)** With increased force of squeezing by the right hand, % BOLD signal intensity and volume of activated pixels in left somatosensory cortex (LSMC) and supplemental motor area (SMA) increased (Fig. 3, 4). Averaged ROI results are shown in Figure 4. In the left SMC, number of activated voxels at 15% (532±116) differed than at 45% (935±116), p=0.046 and both differed from 60% (1517±116), p<0.00005; %BOLD at 15% differed from %BOLD at 60% (p=0.020). In SMA, the 15% and 60% levels differed significantly both by number of activated voxels (p=0.038) and by %BOLD (p=0.003) (P = 0.05 using repeated-measures ANOVA and a Bonferroni correction to protect against Type-I errors from multiple comparisons)

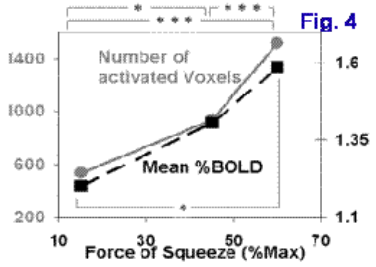

Figure 4: The mean number of significantly activated pixels and the mean weighted % BOLD signal in left SMC increase with % of maximum force of squeezing at 3T. Our optimized protocol affords improved signal and spatial specificity of motor fMRI of squeezing which may eventually provide accurate, sensitive and specific information into the effectiveness of rehabilitation therapy of humans with motor deficits.

Discussion: An "optimized" EPI protocol using GRAPPA, suitable for whole high-spatial resolution, whole-brain coverage, BOLD fMRI, is presented. We have validated our protocol against a "standard" non-GRAPPA EPI and have measured motor cortex activation versus force of squeezing at 3T. Our optimized protocol affords improved signal and spatial specificity of motor fMRI of squeezing which may eventually provide accurate, sensitive and specific information into the effectiveness of rehabilitation therapy of humans with motor deficits.

References

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