On the application of TGRAPPA in functional MRI

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Introduction As one major technique of parallel imaging, GRAPPA[1] has been extensively applied to functional MRI. The benefit of parallel imaging in fMRI includes higher spatial/temporal resolution and less susceptibility artifacts. The acquisition scheme of GRAPPA for fMRI is slightly different from those in most of other applications – the reference scans are taken at the beginning of the fMRI run and the GRAPPA weights computed from these reference scans are used for all image reconstruction thereafter. No autocalibration signal (ACS) lines are needed for the image scans because there is little change in the fMRI images. This approach is very effective, but it comes with a drawback - if the subject has significant head movement during the reference scans, a severe artifact will appear in the images for the entirety of the run in a similar pattern (Fig. 1), leading to higher temporal noise. This can be a problem for imaging with children or special patients. To avoid susceptibility to reference scans, a time interleaved sampling scheme can be used as proposed in the technique TGRAPPA[2]. While still using the GRAPPA reconstruction scheme for fMRI, the ACS lines can be from either the reference scans or combined from the image scans, whichever has the least motion. The feasibility of applying TGRAPPA in fMRI is discussed in this work.

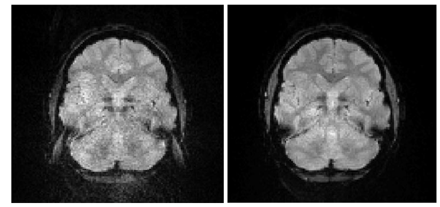

Fig. 1. Images from two different runs of an fMRI exam. All the images in the same run look the same.

Methods The pulse sequence of TGRAPPA for fMRI was modified from the EPI sequence. The time interleaved sampling was accomplished by changing the pre-phase gradient in the phase encoding direction so that the encoded k values are shifted according to the following relation $\Delta k = \mathrm{mod}(n, AF)$ where n denotes the image number in an fMRI run and AF indicates the acceleration factor. Echo shifting was applied to the k-space lines with $\Delta k > 0$ to reduce phase errors[3]. All the images were acquired on a TIM Trio System using a 12-channel head matrix (Siemens Medical Solutions, Erlangen, Germany). TGRAPPA was tested on an ACR phantom (one slice, 100 repetitions, AF = 2, 3) and a human subject with block-design visual stimuli (29 slices, 150 repetitions, AF = 3). The human subject was instructed to move his head freely during the reference scans. For comparison purposes, an identical fMRI run was conducted on the same subject using GRAPPA acquisition. All raw data from TGRAPPA were saved for off-line reconstruction. The GRAPPA weights were calculated from the ACS lines using 12 neighbors. For EPI scans, residual phase offset between odd and even echoes still exists even after correction with phase reference scans. The residual phase errors may have different impact on the interleaved k-space. Hence, the reconstruction is done in two different ways to find a better solution. The first approach (recon1) is the standard GRAPPA algorithm where all ACS lines are indiscriminate; one set of GRAPPA weights are computed from all the ACS lines and applied in all image reconstruction. The second approach (recon2) divides the ACS lines into different groups that match different time interleaved sampling patterns (e.g., for AF = 2, the odd lines will be in group 1 and even lines in group 2). The GRAPPA weights are calculated separately for each group and applied to the corresponding under-sampled k-space separately. To evaluate the performance of TGRAPPA in the presence of motion during reference scans, two sets of fMRI data were reconstructed using ACS lines from the reference scans and ACS lines from the image scans with minimum interscan motion (based on output of motion correction of dataset 1).

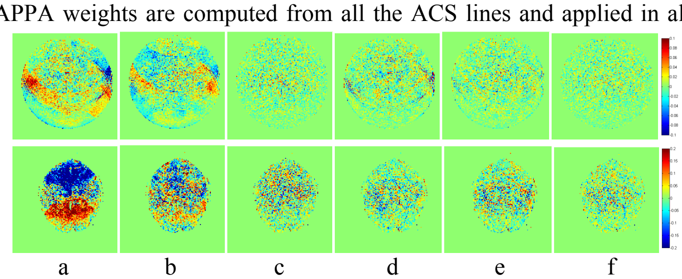

Fig. 2. Differences images for a phantom (top row) and human brain (bottom row) with AF 3. Results from recon1 are shown in (a)-(c) and results from recon2 are shown in (d)-(f). (a) and (d) dif(1,2); (b) and (e) dif(1,3); (c) and (f) dif(1,4); Here dif(n1,n2) is defined as (image n1 minus image n2)/(image n1).

Results Fig. 2 displays the difference images from a subtraction of two images for both phantom and human brain. The results show that conventional GRAPPA reconstruction using the same GRAPPA weights can cause signal variation between the time interleaved scans (Fig. 2a and 2b), which is much bigger than the difference image expected for GRAPPA (Fig. 2c). The variation can be significantly reduced using separate reconstruction (Fig. 2d-2f). Therefore, the temporal noise for TGRAPPA is affected by two major factors. One is the g-factor of GRAPPA reconstruction. The other is the signal jump from time interleaved sampling. Because of the signal jump, the temporal noise for TGRAPPA is greater than GRAPPA as shown in Fig. 3. However, this is not true if there is motion during the GRAPPA reference scans. If the head moves in the phase encoding direction by one pixel in one of the reference scans, the temporal noise can be much higher than TGRAPPA with recon2. Comparing Fig. 3c and 3d suggests that using more ACS lines helps to lower the temporal noise slightly. The fMRI activation maps in Fig. 4 show that TGRAPPA detects less functional activation than GRAPPA. This is mainly due to the higher temporal noise in TGRAPPA. Fig. 4a demonstrates that motion in the reference scans can significantly lose the statistical power, which can be restored by using image scans for autocalibration.

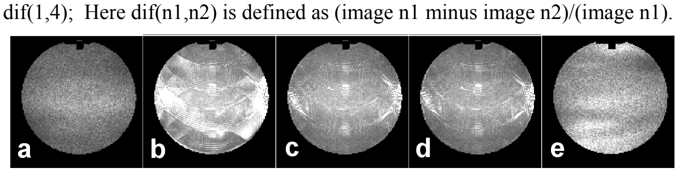

Fig. 3. Temporal noise of the phantom scans for AF 3. (a) GRAPPA sampling; (b) TGRAPPA sampling, recon1; (c) TGRAPPA sampling, recon2 with 48 ACS lines; (d) TGRAPPA sampling, recon2 with 124 ACS lines; (e) GRAPPA sampling, but with motion of one pixel displacement in one reference scan.

Discussion TGRAPPA can be used in fMRI as an alternative for GRAPPA by using appropriate reconstruction scheme. Because of the phase errors in EPI scans, TGRAPPA tends to have higher temporal noise than GRAPPA. However, TGRAPPA can retrospectively correct motion artifacts produced during the reference scans.

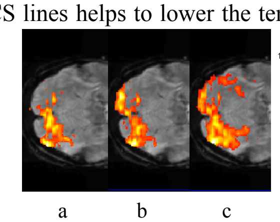

Fig. 4. Activation maps on the same slice ($P < 0.001$) for (a) TGRAPPA, ACS lines from reference scans; (b) TGRAPPA, ACS lines from image scans; (c) GRAPPA.

References

1. Griswold MA, et al., MRM. 47:1202-1210 (2002). 2. Breuer FA, et al., MRM. 53:981-985 (2005). 3. Feinberg DA, Oshio K, MRM. 32:535-539 (1994).