Interactions between Physiological Noise Correction and GRAPPA Reconstruction in EPI Data

R. Allen Waggoner[1], Zhentao Zuo[2], Yan Zhuo[2], Topi Tanskanen[1], Kenichi Ueno[3], Keiji Tanaka[1], and Kang Cheng[1,3]

[1]Laboratory for Cognitive Brain Mapping, RIKEN - Brain Science Institute, Wako-shi, Saitama, Japan, [2]State Key Laboratory of Brain and Cognitive Science,Beijing MRI Center for Brain Research, Institute of Biophysics, Chinese Academy of Sciences, Beijing, Beijing, China, [3]RRC, RIKEN - Brain Science Institute, Wako-shi, Saitama, Japan

Target Audience: Neuroscientists and physicists using physiological noise correction and GRAPPA reconstruction in EPI based fMRI.

Purpose: Physiological noise correction (PNC)[1,2] is now commonly used to minimize the variance in fMRI data. The correction is most often performed in image space (RETROICOR)[2], however this methodology was originally developed as a k-space based correction (RETROKCOR).[1,2] GRAPPA[3] is widely used to accelerate the EPI data acquisition. The ACS lines are usually acquired in a separate scan to allow for higher acceleration, however this temporal mismatch between the calibration data and the fMRI data could potentially allow physiological noise to degrade the GRAPPA reconstruction. Since the output of the GRAPPA reconstruction is still k-space data, k-spaces based PNC can potentially be applied either before or after GRAPPA reconstruction. To explore the influence of physiological noise on the GRAPPA reconstruction of EPI data, we have applied PNC at various points in the processing pipeline of both normal GRAPPA reconstructed EPI data and data with temporally updated GRAPPA weights (tGRAPPA[4]).

Methods: Three female subjects (32±8 yrs.) were scanned to acquired EPI time series on either a 7T (Siemens; Erlangen, Germany) or a 4T (Agilent; Santa Clara CA, USA) whole-body MRI system. At 7T one data set was acquired using a 24-channel whole brain receive array (Nova Medical, Wilmington MA, USA), this data set contained 300 time volumes each containing 24 slices with a 3mm isotropic resolution, a TR of 2s, a TE of 21ms and an acceleration factor of 3. This 7T data was reconstructed using an in-house GRAPPA routine and PNC was performed in three ways, on the k-space data before GRAPPA reconstruction, on k-space data after reconstruction, or on image space data. At 4T four data sets were acquires from two subjects, using a 16-channel whole brain receive array (Nova Medical, Wilmington MA, USA),. Each of the 4T data sets contained 320 time volumes, 40 slices, and an isotropic resolution of 3mm. For each subject two data sets were acquired with separate acceleration factors, R = 2 and 4. In both runs the TR was 2s and TE was 25ms. The data at 4T was acquired using a tGRAPPA acquisition strategy, which allows for temporal updating of the GRAPPA weights. The 4T data was reconstructed in two different ways, a GRAPPA reconstruction like the 7T data where a single set of GRAPPA weights from the initial volume was used to reconstruct all volumes, or the tGRAPPA reconstruction where optimized GRAPPA weights were determined for each volume. PNC was performed on the GRAPPA reconstructed data the same as on the 7T data. PNC was done before the tGRAPPA reconstruction and RETROICOR was performed on the data that had already been corrected with RETROKCOR. To assess the PNCs, relative variance maps, rvar = $\sigma^2_{PNC}/\sigma^2_{noPNC}$, were calculated.

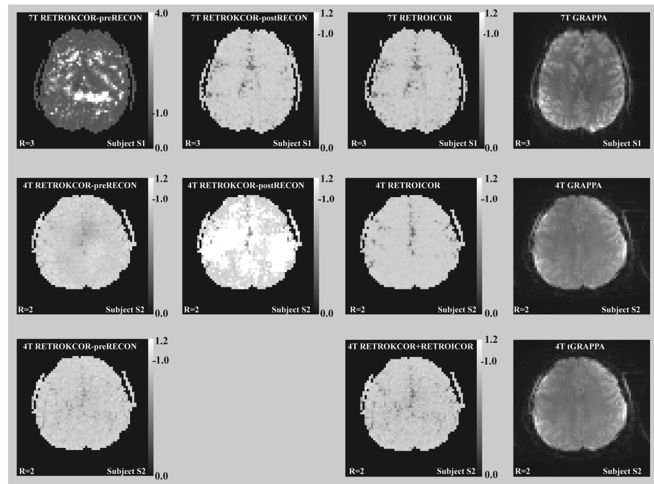

Fig. 1 Sample rvar maps for single slice from the 7T data (top row) and 4T data (bottom 2 rows). 1st column PNC before GRAPPA, 2nd column k-space PNC after GRAPPA, 3rd column image-space PNC. The bottom row is for tGRAPPA and the 3rd column rvar map is k-space + image-space PNC.

Table 1 Mean and standard deviation of each rvar map. The cells in red indicate reconstruction and PNC combinations that amplified than reduced noise.

Relative Variance for various reconstruction Strategies						
Subject		GRAPPA RETROKCOR pre-Recon	tGRAPPA RETROKCOR pre-Recon	GRAPPA RETROKCOR post-Recon	GRAPPA RETROICOR	tGRAPPA RETROKCOR + RETROICOR
S1 (7T)	R=3	1.67 ±1.52		0.92 ± 0.11	0.90 ± 0.10	
S2 (4T)	R=2	0.96 ± 0.07		1.17 ± 0.42	0.94 ± 0.09	
	R=2		0.96 ± 0.06			0.93 ± 0.08
	R=4	0.99 ± 0.04		3.86 ± 4.24	0.96 ±0.05	
	R=4		0.99 ± 0.05			0.96 ± 0.05
S3 (4T)	R=2	0.97 ± 0.10		1.10 ± 0.27	0.95 ± 0.04	
	R=2		0.92 ± 0.08			0.88 ± 0.09
	R=4	0.98 ± 0.06		1.73 ± 1.02	0.95 ± 0.06	
	R=4		0.98 ± 0.06			0.94 ± 0.06

Results & Discussion: Fig. 1 shows sample rvar maps for a slice from 7T data set (top row) and sample slice from the R=2 reconstructions of one subject at 4T (GRAPPA: middle row; tGRAPPA: bottom row). Table 1 shows the mean and standard deviation of each rvar map for each subject. If the PNC worked properly each pixel in an rvar map should be between 0.0 and 1.0. For the GRAPPA reconstructions with RETROKCOR, this is not always the case, indicating that when the GRAPPA weights are not optimized for each time volume, PNC and GRAPPA reconstruction can interfere with each other. At 7T applying RETROKCOR before GRAPPA reconstruction caused an amplification of σ^2, and at 4T the amplification happened when the PNC was applied after GRAPPA reconstruction. This disparity indicates that the physiological noise is represented differently in different data sets. This may be because slice orientation influences the way respiratory noise is distributed in k-space. With the tGRAPPA reconstruction PNC did not interfere with the GRAPPA reconstruction. The third column in Fig. 1 shows that RETROICOR is more effective near blood vessels, therefore for cardiac noise correction. The bottom rvar map in the first column shows that RETROKCOR reduces the variance uniformly, therefore is more effective for respiratory noise correction. The bottom rvar map in the third column shows the relative variance when both RETORKCOR and RETROICOR have been applied to the tGRAPPA data, illustrating that when both corrections can be done a more thorough PNC is achieved. However, as summarized in Table 1, in most cases this reduces the mean rvar by less than one standard deviation.

Conclusions: When a static set of GRAPPA weights is used to reconstruct an EPI time series, as is usually done in fMRI, k-space based PNC can interact with the GRAPPA reconstruction to actually amplify the noise rather than reducing it. The use of optimized GRAPPA weights for each time volume eliminates this interaction, thus allowing for effective k-space based PNC. In the absence of temporally optimized weights only image-space based PNC should be done in combination with GRAPPA reconstruction, which is what is normally done anyway. In summary, tGRAPPA or other GRAPPA based techniques that allow for temporal updating of the GRAPPA weights can lead to a more thorough PNC.

References:

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