Investigation of GRAPPA g-factor dependence on calibration scan phase errors and SNR

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Target Audience: Researchers using accelerated MRI techniques.

Purpose

Current EPI based fMRI protocols frequently incorporate accelerated acquisitions using GRAPPA (1). Recently, it has been shown that the temporal SNR (tSNR) of GRAPPA EPI data can be highly inhomogeneous and significantly compromised when using a GRAPPA calibration scan based on an EPI acquisition scheme (2)**.** This effect was attributed to the presence of uncorrected phase errors in the calibration data that propagate into the GRAPPA kernel calculation. It is known that the GRAPPA kernel determines the additional noise penalty (*g*-factor), and hence the tSNR (3)**.** Additionally, it has been shown that the tSNR of GRAPPA EPI can be improved by using a calibration scan based on a FLASH acquisition scheme rather than an EPI acquisition scheme (2). In this work, we investigated the dependence of GRAPPA *g*-factor on the phase errors and SNR of the calibration scan.

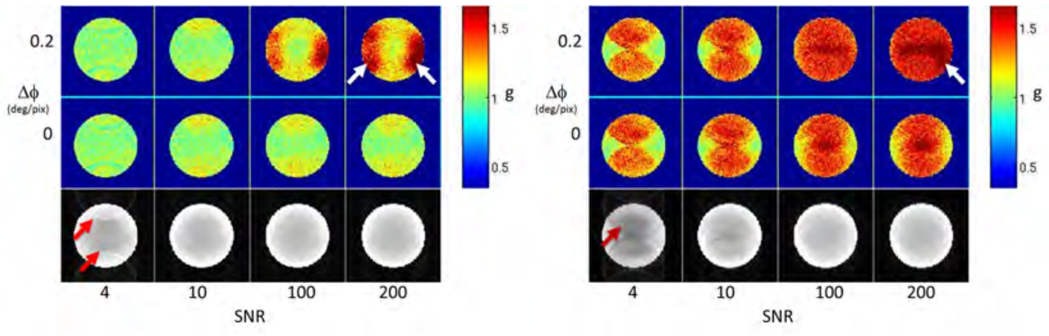
Method

Computer simulations were performed using an idealized 16 element receiver array represented as a set of wires equally spaced on a cylindrical surface (diameter 22 cm). An image (FOV = 25.6 cm, matrix = 128 X 128) of a circular phantom (diameter 17 cm) from each coil element was generated assuming that the signal intensity at each pixel is inversely proportional to the distance between the pixel and the coil location. The simulated coil images were 2D Fourier transformed, replicated (100 repetitions) and combined with random noise to generate a k-space time series without acceleration. Accelerated (R=2 and 3) k-space data were created by extracting every second or the third line from the data without acceleration. To simulate an EPI acquisition, a linear frequency dependent phase shift was introduced between the odd and even lines. A GRAPPA calibration data were created by taking the center 64 lines of the k-space data without acceleration. Calibration scans with and without a phase-shift between the odd and even lines were created to simulate calibration data acquired with EPI and FLASH acquisition schemes, respectively. The phase errors were applied only to data in certain coil elements (see Fig. 1 caption). In addition, calibration k-space data of different SNR levels were also created. Each calibration data set was used in GRAPPA reconstruction of the accelerated k-space data using a kernel size of 3 X 4 (3). GRAPPA weights were calculated by inverting the source data matrix via Moore-Penrose pseudoinverse. The g-factor map corresponding to each calibration data set was calculated as the ratio of the tSNRs of reconstructed images without and with acceleration scaled by 1/$\sqrt{\text{R}}$. Simulations were performed using MATLAB.

Results

Figure 1 shows the mean images and *g*-factor maps for R=2 and R=3. As expected, for R=2, when there is no phase error between the alternating lines in calibration data (simulating a FLASH acquisition), the *g*-factor values are very low for all SNR values of the calibration scan (Fig. 1A, middle row). However, when using a calibration scan with 0.2 deg/pixel phase error (simulating an EPI acquisition), areas of high *g*-factor values are obtained at higher SNR values (Fig. 1A, top row, white arrows). This level of phase error produced ~5% of ghost in the calibration scan images (not shown). At lower SNR values of the calibration scan, the GRAPPA reconstructed images exhibit ghost artifacts (Fig. 1A, bottom row, red arrows) while the *g*-factor values are unaffected by the phase error in the calibration scan (Fig. 1A, left column). Similar results were obtained for R=3 (Fig. 1B). R=3 data show generally higher g-factor values along with additional areas of higher *g*-factor when the calibration scan SNR is high and has a phase error (Fig. 1B, top row, white arrow).

Simulations also show that the areas closest to the coil elements with phase error in the calibration data exhibit high *g*-factor. Therefore, the overall spatial pattern of the high *g*-factor regions depends on the particular coil elements with phase errors in the calibration data. The coil elements with phase error in data shown in Fig. 1 were chosen to match the experimental data reported previously (2).



(A) (B)

Fig.1: Simulated GRAPPA mean images (bottom row) and *g*-factor maps (middle and top row) for R=2 (A) and R=3 (B). Different columns correspond to different SNR values of the calibration scan. Different rows of *g*-factor maps correspond to linear phase error of 0 and 0.2 deg/pixel between the alternating lines of calibration data. The phase errors were applied only to data in coil elements 3,4,6,7,12-15. Coil elements are numbered clockwise with element 1 in 6 o'clock position. Phase encoding direction is vertical.

Discussion

Simulation data shown here indicate that phase inconsistencies in the calibration scan can lead to high *g*-factor and hence, lower tSNR, in the GRAPPA reconstructed EPI data. These results confirm that reduced tSNR observed in experimental data reported previously (2) is due to phase errors in the calibration scan. The simulations also show that the detrimental effect of calibration scan phase error is more prominent at higher SNR. Therefore, these effects are expected to be more important in GRAPPA EPI scans acquired at lower resolutions and/or at higher field strengths. As demonstrated previously, a FLASH acquisition scheme can be used to acquire GRAPPA calibration data without phase error and restore tSNR in the reconstructed images (2).

References: 1) Griswold et al., MRMl. 47:1202 (2002). 2) Talagala et al., ISMRM 21:2658 (2013). 3) Breuer et al., MRM 62:739 (2009).