Effects of Motion on Coupling of Coil Elements and Parallel Imaging Reconstruction at 3T and 7T

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Introduction: For long time series acquisitions such as those used for DTI or FMRI, generally only one set of parallel imaging (PI) reference data (sensitivity map or auto-calibration signal (ACS) lines) are acquired at the beginning of the scan. Any motion during the acquisition of the reference data or the under-sampled images deteriorates image fidelity. However, the effects of motion between the acquisition of reference data and under-sampled images are not well characterized. In theory, as long as the relationship between different coil channels does not change, the reference data should still be valid and provide faithful reconstruction of the under-sampled images. However, depending on the design of the coil, movement of the subject's head closer or farther away from certain coil elements can alter the loading of coil elements and lead to changes in the coupling between them, thereby changing the relationship between the coil elements (previously measured by the reference scan) and leading to artifacts in the reconstruction of the under-sampled images. We demonstrate the artifacts that result from motion between the ACS lines and the under-sampled images. We also examine the relative strength of these effects at 7T compared to 3T. Lastly we relate the change in noise correlation between coil channels to image fidelity.

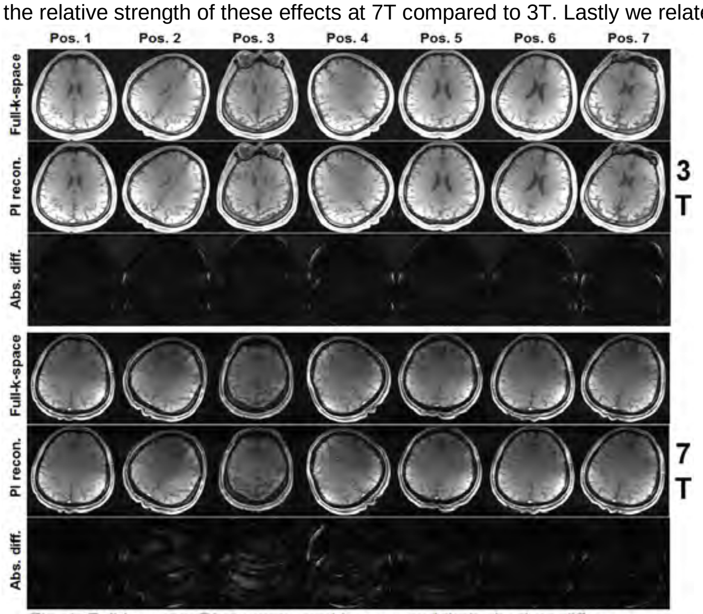

Fig. 1, Full-k-space, PI reconstructed images and their absolute difference.

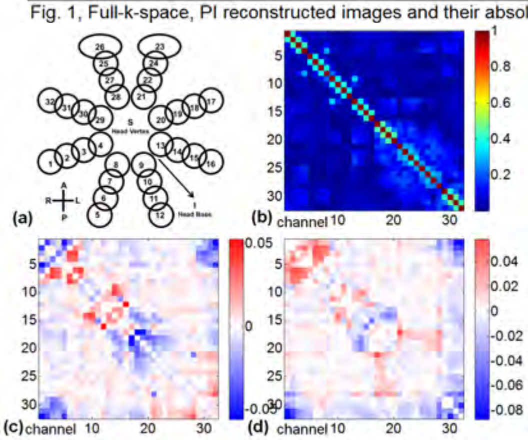
Fig. 2, (a) coil element layout, (b) noise correlation matrix at Pos. 1 and the difference between Pos. 2 (c) and Pos. 4 (d).

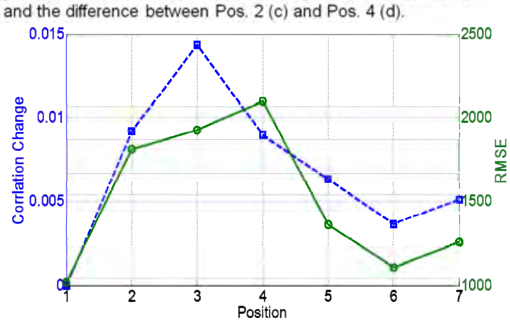

Fig. 3, Noise correlation change from Pos. 1 versus the RMSE between full-k-space and PI reconstructed images at 7T.

Theory: ACS lines reflect the coupling between coil elements, which consists of direct capacitive and inductive coupling between coil channels and indirect resistive coupling through the object when two coil channels possess overlapping spatial sensitivities. In well-tuned coils that minimize the direct coupling, the indirect resistive coupling is the dominant factor affected by the coil loading and in turn subject motion. Since the noise captured by each coil element is independent and identically distributed, any correlation between the noise from different coil channels is therefore reflective of coil channel coupling. As such, noise correlation provides a measure of the coil channel coupling and an indirect measure of subject motion.

Methods: *Acquisition*: Data were acquired on a 3T MR750 and 7T MR950 whole body MRI scanners (GE Healthcare) each equipped with a 32-channel phased-array head coil (Nova Medical) on a healthy volunteer (26 y.o male). T_1-weighted images were acquired using an MP-RAGE sequence. Full k-space data were acquired at seven different head positions (Fig. 1 1^{st} and 4^{th} row) with intentionally exaggerated motion that is rare in practical applications but facilitates a clear demonstration of the motion effects. The under-sampled images were simulated retrospectively by sub-sampling the full k-space data offline. The sequence parameters were: TE/TR/TI=3.2/2500/1100ms, α=18°, 30 slices, FOV=192mm×192mm, matrix size=256×256, slice thickness=0.8mm. Noise data for each head position were acquired after turning off the RF exciter. *Analysis*: For one slice of interest, the k-space was sub-sampled to simulate R=3 in the PE direction. ACS lines (48×48 in the center k-space) from the normal head position (Pos. 1) were used to perform the PI reconstruction for all positions using SPIRIT[1] with 5×5 kernel size. Images from different coil channels were combined using root-sum-of-squares.

Results and Discussion: The full-k-space images, the PI reconstructed images and the absolute difference maps are shown in Fig. 1 on both 3T and 7T. Residual aliasing was observed for every significant head position change. The artifacts were minimal at 3T without obvious visual difference but more significant at 7T. Fig. 2 depicts the noise correlation matrice at Pos. 1 (b) and the difference between the noise correlation matrix at Pos. 2 versus Pos. 1 (c) and at Pos. 4 versus Pos. 1 (d). As expected, the correlation matrices show that coil elements that are located more closely together (as shown by the geometry in Fig. 2a) show higher correlation coefficients in the correlation matrices. From Pos. 1 to Pos. 2, the head moves towards to the left, such that the coupling among channels 1-4 and 17-20 is decreasing while the coupling among channels 13-16 and 29-32 are increasing. When the head moves towards to the right from Pos. 1 to Pos. 4, the increasing and decreasing of the coupling among the elements behaves oppositely. Therefore, the correlation change encodes the information about motion. Fig. 3 shows the average correlation change between all coil elements from Pos.1 versus the RMSE of the 7T data reconstructed using the PI reconstruction with ACS lines from Pos. 1 versus the full-sampled k-space data. At Pos. 2-5, the head motion is large therefore the noise correlation changes significantly and the reconstructed PI images are of worse quality. At Pos. 6 the head is in a very similar position to Pos. 1 and therefore the noise correlation change and RMSE is decreased. For Pos. 7, the head rotates and the noise correlation change and RMSE is slightly increased again.

Conclusions: We demonstrate that subject motion between the acquisition of ACS lines and under-sampled images can result in residual aliasing in reconstructed PI images. These artifacts were found to be more significant at 7T compared to 3T. Increased changes in the noise correlation correlates with the severity of artifacts observed in the reconstructed images therefore could potentially be used to determine whether a new set of ACS lines should be acquired.

Acknowledgments: We thank Ron Watkins, James Rioux and Brian Rutt for helpful discussion. Funding was provided by the Li Ka Shing-Oxford-Stanford Big Data in Human Health seed grant, Stanford Radiology Angel Funds, GE Healthcare, NIH: P41-EB015891, S10-RR026351. **References:** [1] Lustig M and Pauly JM, MRM 64(2): 457-471, 2010.