Can relative coil-subject motion during acquisition improve Parallel Imaging?

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Introduction: Partially Parallel Imaging (PPI) enables reconstruction with reduced phase encoding steps (1) but with a signal-to-noise-ratio penalty. Besides the expected reduction with the square root of the acceleration factor, an extra factor appears (the g-factor) which is dependent on the geometry of the coils (2). Here we show that in certain circumstances it is possible to reduce the level of noise amplification in a multi-shot acquisition by applying a relative rigid body translation between the coils and the subject from shot to shot. This type of motion is typically produced with multi-station moving table acquisitions (3).

Methods: The concept was explored through a set of simulations using an MNI phantom image (4) and eight coils with synthetic Gaussian profiles arranged in two linear arrays as shown in Figure 1. A two-shot acquisition was considered with phase encode A-P and the object displaced between shots relative to the reference position by either $-M$ or $+M$ pixels along either the read or the phase encode direction. To mimic the effect of acquiring different portions of k-space at different positions relative to the coils, for each shot a replica of each coil image was multiplied by the required phase ramp. The k-space lines corresponding to each shot were then extracted and combined to form the reduced k-space. At this stage Gaussian noise was added. The G-SMASH algorithm (5) was employed to recover the fully-encoded image, as a k-space method was needed to accommodate shot by shot motion. In this process the object was viewed as static in the reference position and the appropriate spatial transformations applied to the coil sensitivities and measured signal. This is similar to Atkinson et al. (6) except that the motion is intentionally applied and therefore known a priori. To determine in which situations motion could help reduce noise amplification, the width of the coil profiles was varied while keeping the spacing between elements constant. The motion amplitude was also varied, taking care to ensure that the object would always remain within the selected field-of-view. To quantify any change in performance the condition number of the reconstruction matrix was monitored. For interesting cases where the condition number was promising, multiple trials with varying random noise were performed so as obtain a reliable estimate of the standard deviation of the reconstructed images. In order to compare the level of noise in the images, the joint entropy between each reconstructed image and the gold standard image was calculated following the same procedure as in (7). The underlying assumption here is that increased noise leads to higher joint entropy.

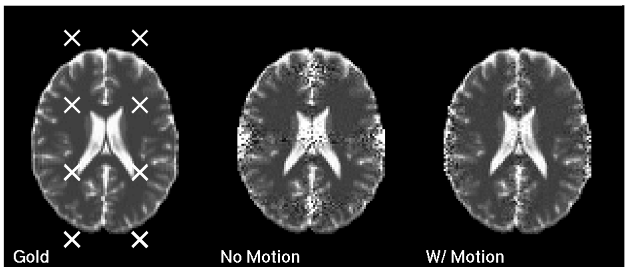

Figure 1. From left to right: gold standard image showing the center of each coil; image reconstructed in the standard way; image obtained when the data for each of the two shots is acquired with the object at a different position relative to the coils. The translations were applied along the phase encode direction (anterior/posterior in this example). A reduction factor of 3.1 was applied.

Results and Discussion: The reconstruction was found to be improved (as assessed through the condition number of the G-SMASH matrices) when the FWHM of the Gaussian profile was lower than the distance between adjacent coils (along the direction of motion). The most significant improvements were observed for motion amplitudes, M equal to 25%, 75%, etc of the coil spacing, which corresponds to the situation when the coil sensitivity for the two positions is the most different. In order to observe significant improvements contiguous k-space lines should be acquired at different positions (i.e. they should be acquired interleaved), as opposed to acquiring, for example, the top half of the sampled k-space at position $+M$ and the lower half at position $-M$.

As an example, in Figure 1 the images reconstructed for a 3.1 times accelerated two-shot acquisition are shown together with the gold standard image displaying the position of the coils. In this example the coil width (FWHM = 30mm) was set to half of the spacing between coils (60 mm) along the phase encode direction, while the two extreme positions were located ± 15 mm from the reference position along the phase encode direction (25% of the distance between adjacent coils). Similar results were obtained for other reduction factors and also for motion along the read direction. Figure 2 shows the noise standard deviation estimated for different positions of the object relative to the coils (first three images) and the motion case (on the right). A very similar pattern is observed for the first three cases, when all the k-space data is acquired with the subject in a fixed position. However, the locations of the maxima vary within the image, depending on the subject's actual position relative to the coils. By shifting the subject in between shots, so that the first interleave is acquired with the subject at the same position as in b), and the second shot with the subject at the same position as in c), the standard deviation over the whole image is significantly reduced. This can be confirmed by comparing the joint entropy values shown in Table 1 calculated for the same coil setup. Following a Normality test (8), the entropy values obtained with and without motion were compared through a paired t-test. The entropy was significantly reduced for the three reduction factors shown when motion was applied between shots ($P<0.01$).

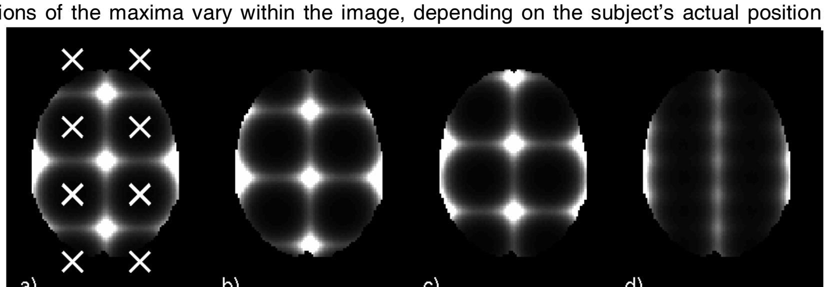

Figure 2. Standard deviation over the 1000 reconstructed images for: a) subject in the reference position; b) shifted anteriorly relative to the coils; c) shifted posteriorly; d) at a different position for each of the two shots.

Conclusions: We have shown that for certain coil configurations motion helps to improve image reconstruction in PPI multi-shot acquisitions. This is counter-intuitive in MRI where object motion is often seen as a confounding factor in image production. Here we exploit the fact that we know the motion exactly and use the information this provides to enhance the reconstruction. A theoretical generalization to link the effect of the motion encoding, Fourier and coil encoding is being sought.

	R=1	R=2	R=3.1
E(Gold, No Motion)	0.314±0.003	0.314±0.003	0.320±0.003
E(Gold, Motion)	0.259±0.003	0.259±0.003	0.267±0.003

Table 1. Mean joint entropy values calculated for the gold standard image versus the images reconstructed for the subject fixed in the reference position or having moved in between the two shots. The error bars correspond to the standard deviation within the 1000 repeats. Each column corresponds to a different reduction factor.

Acknowledgements: EPSRC and Philips for grant funding. **References:** (1) Sodickson DK, Manning WJ, 1997, MRM, 38:591; (2) Pruessmann KP et al., 1999, MRM, 42:952; (3) Dietrich O, Hajnal JV, 1999, ISMRM, 1653; (4) http://www.bic.mni.mcgill.ca/brainweb; (5) Bydder M et al., 2002, MRM, 47:160; (6) Atkinson D et al., 2004, MRM, 52: 825; (7) Larkman DJ et al., 2006, MRM, 55:153; (8) Conover WJ, Practical Nonparametric Statistics. Wiley, 1980.