Auto-calibrated multiband imaging

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Target Audience: Scientists and clinicians interested in accelerating time series acquisitions through multiband imaging.

Purpose: Multiband imaging includes the simultaneous acquisition of multiple two dimensional slices of an object through parallel imaging methods [1,2,3,4]. The use of a unique radiofrequency phase to tag each slice in a packet of simultaneously excited slices adds a degree of freedom in the unaliasing problem [3]. Beyond an additional degree of freedom, the temporal modulation of slice-wise phase tagging enables separation of the parallel acquired slices through the mathematics of Hadamard encoding [5]. In this work, we use Hadamard encoding to yield an auto-calibrating multiband acquisition technology.

	Slice 1	Slice 2	Slice 3	Slice 4
Modulo(repetition,4)=0	0	90	180	270
Modulo(repetition,4)=1	0	90	0	90
Modulo(repetition,4)=2	0	270	180	90
Modulo(repetition,4)=3	0	270	0	270

Table 1: Relative excitation phases for each slice within a packet for each acquired repetition.

Methods: Scans were performed on a 3.0T General Electric Discovery MR750 imager with a 32-channel head coil and body transmit coil. The product echo planar imaging pulse sequence was modified to replace the excitation pulse with a custom designed multiband pulse. The multiband pulse included the excitation of four axial slices as two packets, displaced by 34 mm, of two neighboring 2 mm thick slices. The excited slice profile relative phase tags, from inferior to superior, are shown in Table 1. A time series imaging an agar phantom for 300 repetitions was acquired with 19.2 cm field of view, 96x96 acquisition matrix, minimum full k-space echo time without ramp sampling (TE 46.2 ms), and 2000 ms repetition time. The central 100 repetitions were reconstructed, following the algorithm shown in Figure 1, with moving average window widths varying from ±2 repetitions to ±86 repetitions in steps of 4 repetitions for generating the Hadamard reference images used in the final SENSE [6] unaliasing. For each SENSE unaliased time series, the average tSNR and the residual correlation between unaliased voxel images were computed.

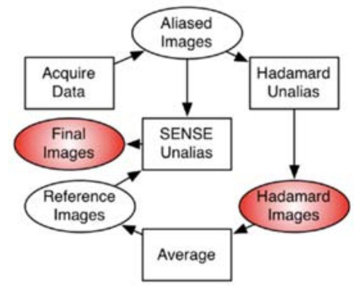

Figure 1: *Auto-calibrated multiband algorithm.*

Results: Hadamard unaliasing yields images that are suitable for use as reference images in subsequent SENSE unaliasing. Plots of the average unaliased time series residual correlation between unaliased voxels and the temporal signal-to-noise ratio (tSNR) are shown in Figures 2 and 3. Results yielding minimal residual correlation between unaliased voxels are obtained with a window width of ±42 repetitions. SENSE and Hadamard unaliased images, along with images of the temporal autocorrelation with a lag of one repetition, and the temporal signal-to-noise ratio of the unaliased time series with a window width of 42 repetitions are shown in Figure 4.

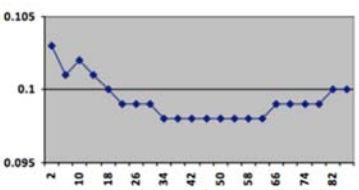

Figure 2: *Temporal correlation between voxels of the final unaliased time series as a function of auto-calibration window width.*

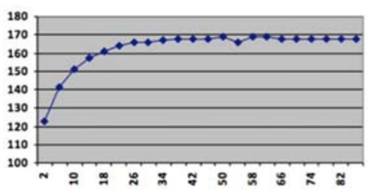

Figure 3: *Temporal signal-to-noise ratio of the final unaliased time series as a function of auto-calibration window width.*

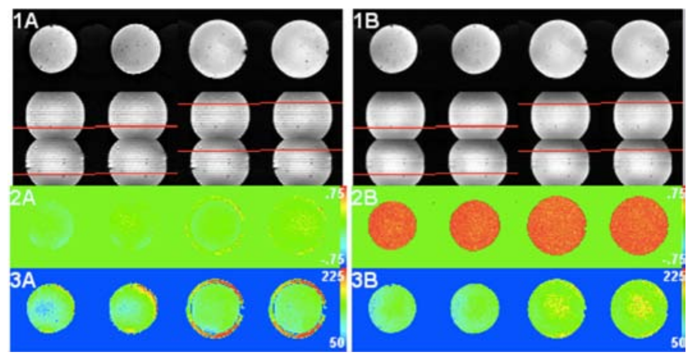

Figure 4: *SENSE (1A) and Hadamard (1B) unaliased multiband images with corresponding time series autocorrolation (2A and 2B), and tSNR (3A and 3B) for a moving average window width of 42 repetitions.*

Discussion: Hadamard and SENSE unaliasing of multiband data are complimentary. Hadamard unaliased images benefit from increased tSNR through effective averaging in the unaliasing process and suffer from increased autocorrelation through that averaging. The opposite is true in SENSE unaliasing, making it more appropriate for time series imaging. Increasing the window width of Hadamard unaliasing for the generation of reference images used in SENSE unaliasing yields increased signal-to-noise ratio in the reference images and better unaliased images. If the imaging system were perfectly stable, reference images generated using the full time series would yield optimal unaliasing. However, system drift, apparent in phase data and consistent with ferroshim heating through thermal contact with the gradient coil that heats with the high duty cycle from frequency encoding in the EPI pulse sequence, puts a limitation on this averaging. With frequency encoding on the X-gradient, this optimal window width that minimizes residual correlation between unaliased voxels was found to be ±42 repetitions. Heating and phase drift have been reduced by an order of magnitude by placing the frequency encoding on the Z-gradient, and the optimal auto-calibrating window width has been found to be significantly broader—at least ±100 repetitions, which is the maximal window width for the given experiment.

Conclusions: These results indicate that the selection of Hadamard unaliasing window width in auto-calibrated multiband acquisition must be empirically selected for a given acquisition paradigm and MRI scanner. With the described equipment and imaging parameters, minimal residual correlation between unaliased slices and high SENSE unaliased time series tSNR were achieved when reference images were generated through Hadamard encoding with a moving average window width of ±42 repetitions.

References: [1] Moeller et al. Magn. Reson. Med. 63:1144-1153 (2010). [2] Feinberg et al. PLoS One. 5(12):e15710 (2010). [3] Jesmanowicz et al. Brain Connect. 1:81-90 (2011). [4] Setsompop et al. Magn. Reson. Med. 67: 1210-1224 (2012). [5] Souza et al. J Comput Assist Tomogr. 12:1026-1030 (1988). [6] Pruessmann et al. Magn. Reson. Med. 42: 952-962 (1999).