Inherent Smoothing in Accelerated Parallel Imaging Reconstruction Techniques

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Introduction: Partially Parallel Imaging techniques are becoming commonly used in many areas of MRI. The two most common reconstruction methods in use are SENSE(1) and GRAPPA(2). Recently Hou et al. (3) pointed out that GRAPPA reconstructions with high acceleration (especially with small numbers of receive coils) can lead to spatial smoothing in the image. Replacing the central portion of k-space with the calibration data (ACS lines), as is usually done in GRAPPA, removes the more obvious reconstruction artifacts but the smoothing remains. In fMRI, spatial smoothing may or may not be a problem, depending on the amount of smoothing and the focus of the experiment, but the presence of unknown smoothing could lead to improper interpretation of the results. TSENSE(4,5) and TGRAPPA(6) are adaptations of SENSE and GRAPPA that allow for continual updating of the calibration data, and in the case of TGRAPPA obtaining higher effective acceleration factors. The acquisition sequence used for TSENSE and TGRAPPA also allows for the possibility of reconstructing the same data with different levels of acceleration. For example a 4-shot EPI acquisition can be reconstructed as a R=1, 2, or 4 data set. Using this approach we have reconstructed fMRI time series at 3 acceleration factors, using both TSENSE and TGRAPPA, and then compared the accelerated data (R=2 or 4) with the non-accelerated data, in order to determine the extent of spatial smoothing that different reconstructions methods are introducing into the data.

Methods: Three sets of EPI time series were collected using three subjects in a Varian Inova 4T (Varian Inc., Palo Alto, CA). A 4-channel "independent" array (Nova Medical Inc., Wakefield, MA) was used to collect the data. The TSENSE images were reconstructed as described by Kellman et al. (4) and the TGRAPPA images as described by Breuer et al. (6). In both cases temporal filtering required for the TSENSE/TGRAPPA reconstruction was done using at notch filter designed to remove the artifacts at the Nyquist frequency, and in the case of R=4, Nyquist/2. For all experiments an image matrix of 64x64 with a 20x20cm FOV was used. The three data sets used auditory paradigms, with the stimulus delivered with Avotec SS-3100 headphones (Avotec Inc., Jensen Beach, FL). The stimulus consisted of either 42 repetitions of 5s of human speech followed by 15s of pink noise or 22 repetitions of 20s of human speech followed by 20s of pink noise. 23 slices (5mm) oriented parallel to the AC-PC line were used to obtain whole-brain coverage. Volume Tr was 2.5s(R=2) or 1.25s(R=4) with TE/FA=25ms/40°. After reconstruction each data set was motion corrected in BrainVoyager QX (Brain Innovation B.V., Maastricht, The Netherlands).

To determine the extent of smoothing in the accelerated data sets, it was assumed each accelerated image was the result of the convolution of the corresponding full k-space image with a 9x9 smoothing kernel. Then for each slice and each time point of each data set, the smoothing kernel could be estimated by deconvolution. The only assumption in determining the kernel was that it is uniform over the slice. Once the smoothing kernel was determined, the central line in both the phase-encode (PE) and read-out (RO) directions were fit with a Lorentzian function in units of pixels of the smoothing kernel in each direction, in order to estimate the half-width at half-height (HWHH). Fig. 1 shows example fits.

Results and Discussion: Fig. 1 & 2 show that there can be significant smoothing in the TGRAPPA reconstruction. In Fig. 2, the blue line at HWHH 1.2 is the time series of the HWHH in the PE (accelerated) dimension for one slice and the red line at 0.95 is the HWHH of the TSENSE reconstruction of the same data, so there can be significant smoothing in the TSENSE reconstruction as well. The green line at HWHH 0.6 is the PE direction TGRAPPA smoothing in the adjacent slice, showing that there is significant variability in the amount of smoothing across slices. Presumably this is a function of the quality of the reconstruction. The other lines around 0.5 are for the HWHH in the RO dimension of the various reconstructions. Even though this is not the accelerated dimension, there is observable smoothing in this direction as well. Table 1 shows the impact of smoothing on the fMRI analysis. For these low resolution data sets, if there is sufficient SNR, the smoothing does not lead to an increased extent of activation (the R=2 case). When the SNR is very low, as in the R=4 case, the extra smoothing in TGRAPPA relative to TSENSE affects the observed extent of activation. For this data, there was a 29% increase in activated voxels.

Conclusions: Both GRAPPA and SENSE reconstructions can lead to spatial smoothing, especially in the accelerated dimension. The use of TGRAPPA and TSENSE can allow the extent of this smoothing to be evaluated in an fMRI time series. In low resolution studies, spatial smoothing may not be a problem, but special care should be taken for high resolution experiments.

Table 1. Comparison of the relative extent of activation (TGRAPPA/TSENSE) and tSNR averaged over the three experiments, at R=2&4

R	relative activation	tSNR
2	0.92	42.2
4	1.29	20.6

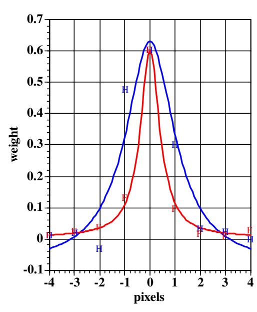

Figure 1. Fitting of the smoothing kernel in both the PE (blue) and RO (red) directions for an example TGRAPPA slice.

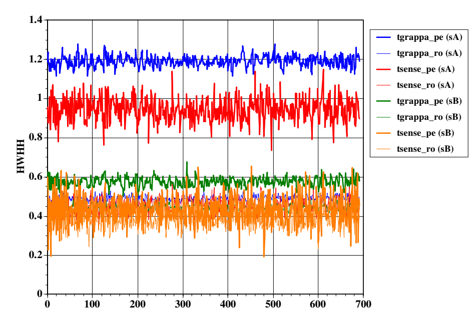

Figure 2. Time series of smoothing kernel half widths for two adjacent slices from one data set.

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