Multi-channel reconstruction in single voxel spectroscopy

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Target audience: Researchers interested in spectroscopy data reconstruction.

Purpose: For single voxel (SV) magnetic resonance spectroscopy (MRS) some methods have been proposed to reconstruct the data from multi-channel systems.(1-3) In this situation, the weighting coefficients of each coil element have been calculated based on signal intensity,(1) signal/noise (SNR)(2) and signal/noise^2.(3) The last case was derived from analytical optimization of the resultant SNR,(3) however uncorrelated noise between channels was assumed. Nowadays, Sensitivity Encoding (SENSE) reconstruction is a common technique used in Imaging(4) and Chemical Shift Imaging,(5) but not in SV-MRS. Here we applied the SENSE principle, which takes account of the noise correlation between channels, as a general approach for SNR optimization of SV-MRS data. Different reconstruction techniques were evaluated using phantom and brain data acquired on a 7T-32channels MR system.

Theory: In single voxel acquisition, the reconstructed spectra (*Sr*) can be considered as a weighted sum of spectra from each coil element (S_i): $Sr = \sum_i w_i \cdot S_i$. In a general case, the weighting coefficients (w_i) can be calculated using the SENSE principle,(4,5) expressed as a column vector: $W = \frac{B^{*T}.\Psi^{-1}}{B^{*T}.\Psi^{-1}.B}$. Here, B and Ψ represent the mean sensitivity of each coil element in the voxel (as a column vector) and the receiver noise matrix, respectively, as described by Pruessmann(4) In the last equation, the denominator is a unique normalization value; the main information of each coefficient is in the numerator. In a particular case of uncorrelated noise, the covariance noise matrix is a diagonal matrix containing the square of the noise of each channel (η_i); thus the coefficient of the i-th coil element is related to: $\frac{B_i^{*T}}{\eta_i^2}$ as suggested by Hall.(3)

Methods: All data were acquired on a Philips Achieva 7T scanner, with a volume transmit and 32-channel receive head coils, from a healthy volunteer and a multi-metabolite phantom (sphere, diameter=8cm).(6) ^{1}H SV MRS data were acquired with different signal averaging (NSA), voxel sizes and positions using the STEAM sequence(TR/TM/TE=2000/17/16 ms, 4096 points, BW=4kHz, 8 phase cycles), with/without water suppression(MOIST, Δf=140 Hz). In the brain, the voxels were positioned in the anterior cingulate cortex (ACC, 20x18x25 mm^3, NSA=288) and the visual cortex (VIS, 20x22x20 mm^3, NSA=288). Spectra from a small voxel (SMV, 20x20x20 mm^3, NSA=40) and a large voxel (LGV, 40x40x40 mm^3, NSA=40) were acquired in the center of the phantom. The noise covariance matrix was calculated from the noise data acquired during the preparation phase. As a noise correlation metric the magnitudes of the correlation coefficients were calculated by considering the covariance and pseudo-covariance matrices. The sensitivity of each coil was estimated from the NAA peak. The SNR of each reconstructed spectrum was estimated as the ratio of the NAA peak amplitude and the standard deviation of a "silent" region (8.7-11.2 ppm) of the spectrum. For comparison, each reconstructed spectrum was normalized by the amplitude of the water peak.

Results: Figure 1 shows the magnitude of noise correlation coefficients for brain (upper) and phantom (lower) cases. Table 1 contains the SNR for each reconstruction approach: *Correlated/Uncorrelated* refers to whether or not the noise correlations between channels is considered; *Sensitivity* means disregarding the noise in the reconstruction; *Maximum channel* refers to the spectrum from the channel with maximum amplitude. Figure 2 shows examples of the reconstructed spectra using different reconstruction approaches from the brain (visual cortex) and phantom (small voxel) data.

Approach	Phantom		Brain	
	SMV	LGV	ACC	VIS
Manufacturer	120	137	37.1	57.3
Correlated noise	122	138	51.7	77.1
Uncorrelated noise	119	138	51.2	76.8
Sensitivity	116	138	50.8	76.5
Maximum channel	44.0	74.7	32.1	51.7

Table 1: SNR estimated in the reconstructed spectra using different reconstruction approaches.

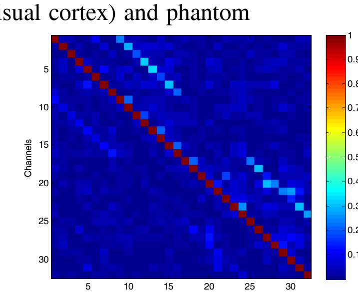

Figure 1: Noise correlation coefficients: Brain (above diagonal) and phantom (below diagonal).

Discussion: As expected, increasing sample size (8cm d.s.v. to head) leads to greater noise correlation between channels (Fig. 1). Even with correlated noise, only a very small difference in SNR was found between weighting approaches. The general shape of the reconstructed spectra is independent of the reconstruction method; however metabolites with very low SNR can be affected. For *in vivo* brain data, reconstructions performed by the scanner have low SNR when compared with the weighting methods, probably, related to the sensitivity of the individual channels.

References: 1. Wijtenburg, S.A. and J. Knight-Scott, Magn. Reson. Imag., 2011; 29: 937-942. 2. Avdievich, N.I. et al. Magn. Reson. Med. 2009; 62: 17-25. 3. Hall, E.L. et al. Neuroimage 2014; 86:35-42. 4. Pruessmann, K.P. et al. Magn. Reson. Med. 1999; 29: 952-962. 5. Dydak, U. et al. Magn. Reson. Med. 2001. 46: 713-722. 6. Barreto, F.R. et al. Brazilian Journal of Biomedical Engineering 2014; 30: 242-247.

Acknowledgments: This work was supported by Fundacao ao Amparo a Pesquisa do Estado de Sao Paulo (2013-19340-6), Brazil.

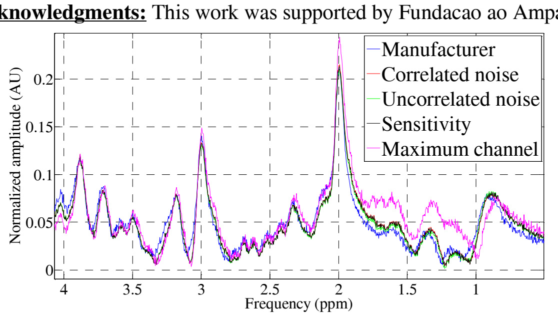

Figure 2: Examples of reconstructed spectra from data acquired on: Anterior cingulate cortex (Left), Phantom (Right).