Investigation of Techniques for Multi Element Coil Combination for 32 Channel 7T MRS

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Introduction: In magnetic resonance spectroscopy (MRS), the acquisition of data from multi-element receive coils is becoming common. As the number of coil elements increases the need arises for robust reconstruction methods. Several methods have been proposed for the combination of multiple coil element spectroscopy data, e.g. [1-4]. The most popular are those that combine data using a simple weighted sum, with weights determined by the signal [1] or signal to noise (SNR) [2] of either the water spectra or from another metabolite [3] (e.g. NAA). Here we use a modification of the SNR combination of multiple coil data to increase signal to noise [5]. This method is demonstrated for proton MRS data acquired using a 32 channel receive coil at 7 Tesla and is compared to three other commonly applied methods.

$$SNR_{total} = \sum_{r=1}^{n} w_r S_r \Big/ \sqrt{\sum_{r=1}^{n} (w_r N_r)^2} \qquad [1]$$

$$\frac{w_1}{w_n} = \frac{S_1/N_1^2}{S_n/N_n^2} \qquad [2]$$

Theory: Equation [1] is the total SNR (SNR_{total}) for the combination of n spectra, with the r^{th} spectra having signal S_r, noise N_r and weighting by factor w_r. By differentiating Eq. [1] with respect to w_r, the optimal values of the weights can be found (Eqn. [2], *maximal-ratio diversity* [5]), which differs from signal to noise weighting, due to the N_r^2 factor rather than N_r.

Simulations: A real spectrum from one subject was used as the basis of the simulations. 32 spectra were simulated by scaling the initial spectrum by a random generated scaling factor (0 – 1), and adding Gaussian random noise with a randomly generated variance (*high* noise, 0.001 - 0.026, and *low* noise 0.001 – 0.005), to give a unique spectrum for each coil (Fig. 1A). The individual spectra were then combined in four ways; equal weighting, signal weighting, SNR and S/N^2 weighted. The signal to determine the weightings was the peak area of the unsuppressed water peak, and the noise was estimated as the root mean square of the last 296 points of the spectra (> 10.4 ppm). Finally, the SNR values of the reconstructed spectra were then calculated as the max of the NAA peak divided by the noise. This was repeated 100 times to give average SNR values, a paired t-test was performed to assess significant differences between the 4 methods. This was repeated for the two noise conditions, *high* and *low*.

Methods: Data were acquired on a Philips Achieva 7.0 T system, with a volume transmit and 32 channel receive head coil, from 8 healthy volunteers (4 M, 24 ± 4 y.o.) all of whom gave informed written consent. The study was approved by the local ethics committee. A single voxel STEAM sequence was used; TR/TE/TM = 2000/16/17 ms, VOI 20 x 20 x 20 mm^3, 4096 point acquisition with a spectral bandwidth of 4 kHz. MOIST water suppression was used, and an unsuppressed water spectra was also acquired. The data were acquired from the visual cortex, the left (L) and right (R) motor cortices and the medial prefrontal cortex, with each acquisition taking 10 minutes (288 averages, N=4 for each location). *Analysis*: The spectra were averaged across phase cycles, zeroth order phase corrected and averaged across acquisitions for each coil. Channel spectra were combined and SNR measured as in the simulations.

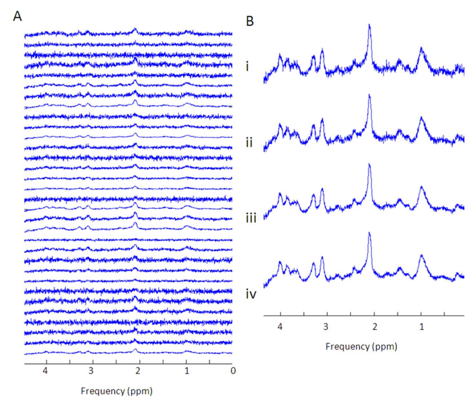

Figure 1: (A) Simulated multi coil data with high noise (B) data combined using (i) equal, (ii) signal (iii) SNR and (iv) S/N² weighting.

Results: Figure 1B demonstrates the reconstructed spectra using four different methods of data reconstruction; equal weighting, signal weighting, SNR and S/N^2 weighting. From the Monte Carlo simulations the average SNR of the four regimes was 14.1 ± 0.2, 16.1 ± 0.2, 26.5 ± 0.6 and 33.8 ± 0.8 (mean ± standard error) for high noise. The S/N^2 weighting gave a significant increase (p<<0.001, paired t-test) in SNR over the over methods, with average improvements of 56 ± 1, 50 ± 1 and 21.0 ± 0.7 % over equal, signal and SNR weighting respectively. For low noise, the average improvements were reduced to 16.1 ± 0.5, 10.4 ± 0.3 and 3.3 ± 0.1 %, but were still statistically different. The SNR of all the subjects for the four coil combination methods is shown in Figure 2. The SNR using the S/N^2 weighting is significantly greater than the other three methods ($P < 0.05$ uncorrected, 2 tailed paired t-test). S/N^2 weighting gave, on average, a 27 ± 3, 8 ± 2 and 1.9 ± 0.9 % increase on SNR compared to equal, signal and SNR weighting respectively.

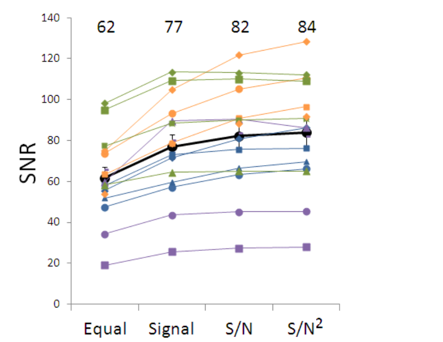

Figure 2: SNR of in vivo data from different VOI locations combined using the different methods. Orange – visual, purple – RH, blue – LH motor and green – medial prefrontal, black - average.

Discussion: The relative improvements given by the proposed method differed by brain region. Voxels in the visual cortex benefited the most, whereas those in the medial prefrontal cortex were relatively unaffected. From the simulations this could be due to the noise contributions in different brain areas, as the coil elements are sensitive to the different voxel positions. Some voxels (Fig. 2) did show slight reductions in SNR with the SNR or S/N^2 methods, this could be due to the difficulty in measuring noise. In addition, this method assumes uncorrelated noise across sensors to allow derivation of Eq. [1], initial investigation has suggested low correlation across the channels (typical magnitude of correlation < 0.2, measured across the 32 channels in one subject), however further investigation is needed.

References: [1] Wijtenburg, S.A. and J. Knight-Scott, MRI, 2011. **29**: p. 937-942. [2] Avdievich, N.I., et al. MRM, 2009. 62: p. 17-25. [3] Deelchand, D.K., et al, J. of Mag. Res., 2012. **206**(1): p. 74-80 [4] Brown, M.A., MRM, 2004. **52**: p. 1207-1213 [5] Brennan D.G. Proc. of the IEEE, 91:2 Feb 2003 P. 331-356. **Acknowledgements:** We acknowledge the Dr Hadwen Trust and the MRC for funding this work. The Dr Hadwen Trust for Humane Research (DHT) is the UK leading medical research charity that funds and promotes exclusively human-relevant research that encourages the progress of medicine with the replacement of the use of animals in research. We thank SoYoung Kim for patient recruitment.