Comparison of different methods for combination of multichannel spectroscopy data

Ioannis Angelos Giapitzakis[1] and Anke Henning[1,2]

[1]*Max Planck Institute for Biological Cybernetics, Tuebingen, Baden-Wuerttemberg, Germany,* [2]*Institute for Biomedical Engineering, UZH and ETH Zurich, Zurich, Switzerland*

INTRODUCTION: Single voxel magnetic resonance spectroscopy (SVS) enables the study of several metabolites in different body parts yielding useful information regarding the underlying biochemical procedures. For reliable quantification and interpretation of the data a high signal to noise ratio (SNR) is required. One solution to this problem is the implementation of phased-array coils. However, one question immediately arising is how the spectra from multiple receive channels can be combined in order to give the best result. **In this study** three different methods for the combination of multichannel SVS data [1-4] were compared with respect to multiple evaluation criteria: 1) Brown's method [2], 2) singular value decomposition (SVD) method [3] and generalized least squares (GLS) method [4] .

METHODS: **First**, a comprehensive analysis of all methods has been performed based on simulated spectra. To that 512 spectra (NEX) were simulated for each coil channel (Fig 1) according to this formula: $FID_{sim} = \Phi * FID_{ref} + R * N$, where $\boldsymbol{FID_{sim}}$ and $\boldsymbol{N}$ are M x P matrices with M being the total number of coil elements and P the total number of the time-points in the FIDs, for this study M = 4 and P = 4096. In particular, $\boldsymbol{\Phi}$ is an M-element column vector containing the initial phase for each coil, $\boldsymbol{FID_{ref}}$ is the reference FID which is a P-element row vector. The simulation of the reference FID was based on a four peak (N-acetyl-aspartate [NAA], creatine [Cr], choline [Cho] and residual water peak [rH_2O]) spectral model. $\boldsymbol{N}$ is an M x P matrix simulating random noise derived from a normal distribution. Finally, $\boldsymbol{R}$ is an M x M matrix derived using the Cholesky decomposition [5] of the noise covariance matrix. Based on an experimentally acquired noise covariance matrix data representing five different noise correlation conditions ranging from low to high coupling between the coil elements were simulated (-4dB, -2dB, 0dB, 2dB, 4dB of the original correlation matrix, Fig 1). In addition, the standard deviation of the noise of each coil-element was different simulating different coil sensitivities. To assess the performance of each coil combination technique three different evaluation criteria were used 1) the SNR of the combined spectrum (amplitude of first time-point / standard deviation of the last time-points in the fid); 2) the Goodness of fit (GoF; $\sqrt{\sum\left(\frac{FID_{combined}}{FID(1)_{combined}} - \frac{FID_{ref}}{FID(1)_{ref}}\right)^2}$); $FID_{combined}$: data of the combined spectra, FID(1): the first time-point of the data 3) the change of the weighting factors across different SNR conditions (NEX). **Finally**, for verification of the simulations in vivo SVS data were acquired (STEAM sequence with a water suppression; TR/TE: 2000/8ms, receiver bandwidth: 8 kHz, NEX: 160, time-points: 4096) using an 8 channel transmit-receive head coil. The experiment was performed on a healthy volunteer using a 9.4T Magnetom SIEMENS scanner.

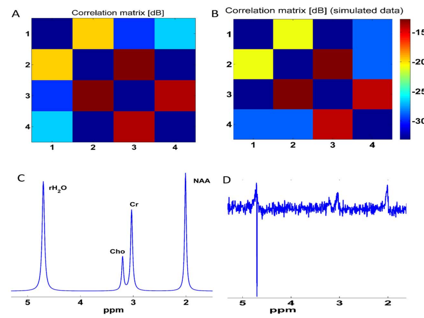

Fig. 1: ***A)*** *Noise covariance matrix of phantom data in dB.* ***B)*** *Noise covariance matrix of simulated data* ***C)*** *Reference simulated spectrum* ***D)*** *Simulated data of one coil-element (NEX=1).*

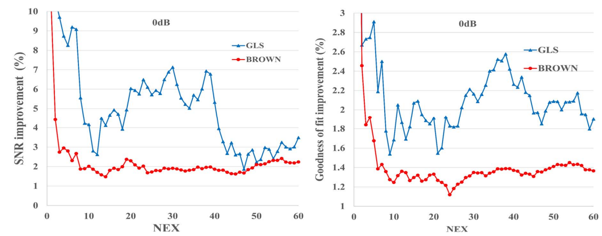

Fig. 2: *SNR and GoF improvement (compared to SVD method) as a function of NEX.*

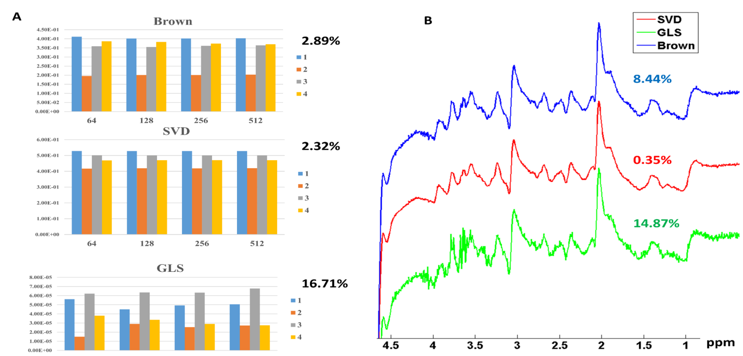

Fig. 3*: A) Change of the real part of the weighting factors. On the x-axis the NEX is indicated. B) Combined spectrum using in vivo data (NEX =160). The number next to the spectrum indicates the change of the weighting factor.*

RESULTS-DISCUSSION: The results of the simulated spectra demonstrate that the GLS method performs slightly better in terms of SNR and Goodness of fit than SVD and Brown's methods for a wide range of coupling conditions (Figure 2, Table 1). However, for very well decoupled coil arrays the SVD method shows the best performance, while for very strongly coupled arrays Brown´s method is the method of choice. The performance of the GLS method varies significantly across different SNR conditions, whereas SVD and Brown's technique seems more stable in this respect (NEX, Fig. 2). Moreover, the change of the real part of the SVD and Brown´s weighting factors were substantially smaller than those of the GLS method across different SNR conditions (Fig. 3). Regarding the in vivo data the results confirmed the robustness of the SVD and also demonstrated that the performance of SVD in terms of SNR is better than the other two methods. This is expected due to the use of a very well decoupled coil array (<-20dB) for acquisition of the in vivo data . Another advantage of the SVD is the better performance in presence of t spurious echoes, which degrade the quality of the spectrum in a specific frequency region close to the water peak (Fig 3B). Brown´s method and GLS could not compensate for this since a specific region of the spectrum is used to calculate the weighting factors. In addition, the performance of GLS depends highly on the selection of the frequency region used for the weighting factors (figure is not shown). Both simulated and in vivo data showed that SVD is more robust than the other two methods confirming also previous studies [3]. In addition, SVD does not need any pre-calculation (e.g. zero phase, calculation of the weighting factors etc.) making its implementation straightforward. Altogether all evaluation criteria are needed in order to conclude on the best possible choice of channel combination method in a specific scenario. Further analysis is required to investigate the performance of the methods in dependence of the number of receive elements.

Coupling (dB)	SNR (%)		GoF (%)	
	GLS	BROWN	GLS	BROWN
-4	1.0	0.9	0.8	0.7
-2	4.2	1.9	1.6	1.1
0	6.4	2.4	2.1	1.5
+2	7.4	8.2	3.3	2.6
+4	7.2	8.2	4.0	5.5
Average	**5.2**	**3.6**	**2.4**	**2.3**

Table 1: *SNR and GoF improvement in simulated data (in % compared to SVD method) as a function of coupling*

REFERENCES: [1] Wright S. *NRMB*. 1997; 52:394-410 [2] Brown M. *MRM*. 2004; 52:1207-1213 [3] Bydder M. et al. *MRI*. 2008; 26:847-850 [4] An L. et al. *JMRI*. 2013; 37:1445-1450. [5] Dongarra et al. *SIAM*. 1979; *LINPACK user's guide*;

ACKNOWLEDGMENTS: *Co-sponsored by the European Social Fund and national funds (NSRF 2007-2013) through the Greek State Scholarships Foundation (IKY)*