FSL-MRS – Tools for Magnetic Resonance Spectroscopy

MRS pre-processing
SVS: before pre-processing

Uncombined coils

Un-averaged repeats

Data shape - $N_{\text{Time Points}} \times N_{\text{Averages}} \times N_{\text{Coils}}$
SVS: after pre-processing

Pre-processing should:
1) Maximise signal-to-noise ratio (SNR)
2) Minimise peak linewidths
3) Reduce baseline and line shape distortion
The water-reference

• Very high SNR water signal
• Water signal experiences (almost) the same acquisition conditions.

Used for:
  - coil combination,
  - eddy current correction,
  - (sometimes) phase and frequency correction,
  - (sometimes) motion correction.

Also must be identically processed to preserve scaling
MRS data has time domain and frequency domain representation.

Conversion via (inverse) Fast Fourier Transform.
MRS data has two channels:
- Stored as complex data,
- Quadrature relationship (90-degree phase offset).
Combine signals with unknown complex (amplitude + phase) weighting. Two approaches:

1. Use ‘fit’ to water reference to derive complex weights.
2. Explicit rank = 1 problem, take first principal component of stacked multi-coil data.
Combining repeated scans

10s to 100s of scans must be combined for sufficient SNR.

**BUT** hardware drift and physiological motion will cause frequency and phase shifts.

[Chemical Shift (ppm) image]
Combining repeated scans: alignment

Small frequency shifts can be “first order” corrected by shifting and phasing individual spectra

Combining repeated scans: alignment
Combining repeated scans: outlier removal

Bad average removal summary

Gross subject motion leads to an incorrectly positioned voxel, severely degraded shim, or both. Corrupted scans should be excluded.
Combining repeated scans: averaging

After alignment and outlier rejection individual scans are combined by taking the mean.
Eddy current artefacts

Eddy currents create time dependent magnetic field during FID collection.
- Easily seen in phase of FID.
- Produces anti-symmetric side peaks in spectrum.
- Corrected by subtracting water reference phase.
Dealing with global frequency shifts

Fitting analysis relies on fitting ‘fingerprints’ with known frequency shifts. Therefore, desirable to eliminate large global shifts.

ECC or incorrect identification of water frequency on scanner can introduce shifts.
Residual water removal

A large residual water peak can distort baseline.

Data-driven fitting approach used to identify and remove residual peak.

FID formed into Hankel matrix representation.

\[
H = \begin{bmatrix}
  s[1] & \cdots & s[K] \\
  s[2] & \cdots & s[K+1] \\
  \vdots & \ddots & \vdots \\
  s[M-K+1] & \cdots & s[M]
\end{bmatrix}.
\]

Then SVD used to identify peak components.

Peaks in water frequency range removed.
Zero-order phase - uniform phase term
Correction applies complex scalar term $e^{j\phi_0}$
Target a purely absorption spectrum for:
1) visualisation and 2) fitting initialisation
Phase correction: 1\textsuperscript{st} order

First-order phase - phase term linear with frequency
Correction applies complex vector $e^{2\pi j \omega \phi_1}$
Equivalent to time shift in time domain.
Spectral editing dynamically alters acquisition parameters.
Combined with differencing to observe obscured metabolites.
Must align two different spectra based on partial similarity.
MRSI Pre-processing

FSL-MRS has limited tools for MRSI pre-processing. All pre-processing tools can be applied per voxel.

Planned features:
- Lipid removal
- Phase correction
- Motion correction