Motion artefact correction in spectroscopic imaging using an EPI navigator and reacquisition

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Introduction: Motion in spectroscopy and spectroscopic imaging introduces three categories of artefacts: i) a localising error where the measured signal is matched to the wrong anatomy; ii) a phase error arising from the excitation process (PRESS / STEAM / LASER) and resulting in phase encoding errors in chemical shift imaging (CSI) and signal cancellation in single voxel averaging; iii) the disruption of the B0 field due to a shift in the susceptibility boundaries. We present a method to correct localisation and remove motion-induced phase errors by using EPI motion correction [1] in a CSI LASER [2] sequence. The sequence tracks motion, corrects the encoding gradients, and the volume selective frequency and phase in real time to follow the moving head. Phase errors will likely occur when there is motion during a TR. By identifying those encoding steps in real time and repeating them immediately until one without motion is acquired, FID's containing phase errors are replaced with uncontaminated FIDs. Previously, phase correction has been done by rephasing the FID during post processing either by using the residual water signal [3] or a secondary non-water-suppressed FID as a navigator [4]. The induced phase error (φ) (in PRESS and LASER) is proportional to the crusher gradient moment (g) and the tissue velocity (v) parallel to the gradient, that is $\varphi = g \cdot v \cdot t \cdot \gamma$, where t is the duration between a pair of crusher gradients and γ is the gyromagnetic ratio. Thus a constant velocity of 2mm/s parallel to the crusher gradient will result in a phase error of 30.9° (g = 138 μTs/m). It should be noted that motion is usually complex and may involve rotations. Rotations about the centre of a VOI are expected to produce continually varying phase errors [3] and are therefore particularly problematic in CSI.

Method: An EPI navigator was inserted before water suppression in a CSI LASER sequence with constant gradients. The 3D EPI navigator parameters were TE = 6.9 ms, TR = 17 ms, BW = 3906 Hz/pix, ETL = 32, matrix = 32x32, slices = 16, ST = 8mm, FOV = 256x256, FA = 2º, total acquisition time (TA) = 300 ms. CSI LASER parameters were as follows: TE = 50 ms, TR = 1500 ms, FOV = 160x200 mm, elliptical phase encoding (16x16 matrix, zero filled to 32x32 for 0.5x0.6 mm in plane nominal resolution) , a Hamming filter = 50, NA = 1, TA = 5min:02s. Offset independent adiabatic pulses (Tp = 4 ms, BW = 6 kHz) based on WURST-8 waveforms [5,6] were used for selection of VOI (80x90x15 mm) due to an improved excitation profile. An absolute measure of motion (m) was calculated using the translation (***t***) and rotation (**R**) about the centre of the VOI and a vector (***v***) equal to ¼ **VOI** (representing the mean effect of rotation), using $m = ||\boldsymbol{t}|| + ||\boldsymbol{v}\cdot\mathbf{R} - \boldsymbol{v}||$. Three volunteers were scanned on a 3T Siemens Tim Trio. The protocol comprised four EPI navigated CSI experiments: i) stationary baseline, ii) motion without correction, iii) motion with motion correction, and iv) motion with motion correction and re-acquisition. The volunteers were trained to rotate their head roughly +/- 8º left-to-right. This motion was chosen to minimally impact the B0 homogeneity. The threshold for re-acquisition was chosen to be 2 mm for the first volunteer and 0.5 mm for the last two. The CSI acquisition slice was chosen to be axial and superior to the ventricles.

For each CSI acquisition with motion, the motion estimate log was used to calculate the mean rate of rotation in deg/s. Signal to noise ratio (SNR) was calculated using the mean energy within the VOI divided by the standard deviation of energy outside the VOI, where energy in a voxel is the integral of the absolute raw FID (without post processing).

Table	SNR			Rate (deg/s)		
Volunteer	**1**	**2**	**3**	**1**	**2**	**3**
Baseline	32.8	32.5	29.1	0	0	0
No Correction	15.7	19.3	24.9	2.43	0.10	1.80
Motion Corrected	16.6	26.2	15.6	2.39	1.38	2.04
Reacquisition	24.9	31.8	31.8	2.42	1.58	2.03

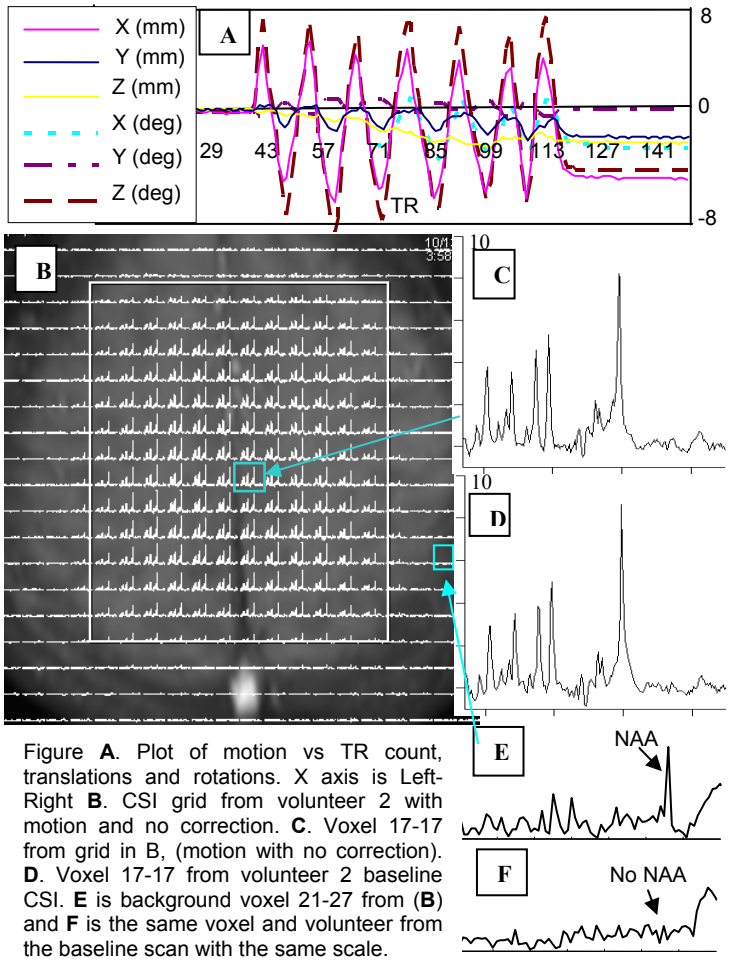

Figure **A**. Plot of motion vs TR count, translations and rotations. X axis is Left-Right **B**. CSI grid from volunteer 2 with motion and no correction. **C**. Voxel 17-17 from grid in B, (motion with no correction). **D**. Voxel 17-17 from volunteer 2 baseline CSI. **E** is background voxel 21-27 from (**B**) and **F** is the same voxel and volunteer from the baseline scan with the same scale.

Results: Figure A shows the motion of a subject. Figure B is the CSI grid acquired for volunteer 2 with motion and no correction, Figure C is a sample spectrum (voxel 17-17, VOI center) from that scan and Figure D is the spectrum of the same voxel from the stationary baseline scan of the same volunteer. The main observable difference between the spectra acquired with no reacquisition and the baseline was a small (~5%) loss in amplitude as demonstrated in Figures C and D. The table gives the SNR and average rate of rotation for each scan and demonstrates the impact of motion on SNR. Figure E is the spectrum from a contaminated background voxel from the same volunteer without correction and Figure F is the same voxel form the baseline scan, the background voxels when reacquisition was employed did not poses this contamination.

Conclusion: It can be clearly seen from the table that motion induces substantial SNR loss, which is not recovered with motion correction alone. The scans with reacquisition at a threshold of 0.5mm have fully recovered their SNR. Volunteer 1 has an SNR improvement with reacquisition but it has not fully recovered, likely as a result of the 2 mm threshold used. These results clearly demonstrate that while a CSI dataset with motion artefact can appear to be fine (Figures B, C), substantial phase errors may be present resulting in significant loss in SNR. Figures B and C have an SNR loss ~25% compared to their baseline scan wile only demonstrating a small change in amplitude, this suggests that SNR is an appropriate measure of phase induced errors. While this dispersion of energy, due to position encoding errors, may not be observable in the spectra, it results in their spatial contamination throughout the volume as demonstrated in the background spectrum of Figure E. EPI motion tracking with reacquisition has minimised the losses in SNR and spatial resolution due to motion.

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