Correction of Motion-Induced Phase Variance in Single-Voxel ^{1}H Spectroscopy

Brian Robert Keating[1] and Thomas Ernst[2]
[1]Department of Medicine, Unversity of Hawaii, Honolulu, HI, United States, [2]Department of Medicine, University of Hawaii, Honolulu, HI, United States

INTRODUCTION

Head motion in MRI and MRS remains a significant problem, particularly for phase-sensitive modalities. Existing prospective motion correction schemes measure the head pose periodically (via MR-based navigator echoes [1] or external tracking systems [2]), and then immediately update gradient waveforms and RF-frequencies in order to maintain the desired positioning of the volume of interest. Such schemes implicitly model the motion trajectory as piece-wise constant; therefore, residual motion which occurs between updates is not corrected for. Uncorrected motion which occurs during gradients causes undesirable, but predictable, phase evolution. In order to investigate the feasibility of using optical motion tracking to correct for such motion-induced phase variation, we performed a number of single-voxel spectroscopy experiments.

THEORY

Assuming the brain moves in an essentially rigid-body manner, its position/orientation can be characterized by a translation vector, **T**(t), and a rotation operator, **R**(t). A spin initially at location $\mathbf{r}_0$ undergoing such motion will experience a phase shift of $\Delta\varphi = \gamma\Delta\varphi_T + 2\pi\gamma\mathbf{r}_0\cdot\mathbf{M}$, where $\Delta\varphi_T = 2\pi\int_0^t \mathbf{G}(t')\cdot\mathbf{T}(t')dt'$ [Eq.1] is the translation-induced phase shift and $\mathbf{M}(t) \equiv \int_0^t \mathbf{R}^{-1}(t')\cdot\mathbf{G}(t')dt'$ [Eq.2] is an extra gradient moment induced by rotational motion.

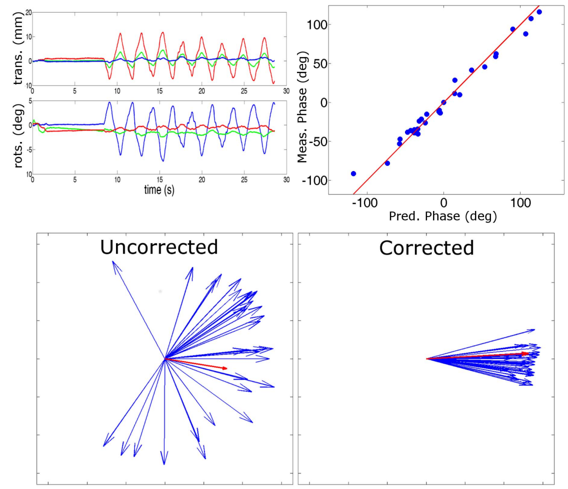

Fig. 1: (a) representative portion of motion trajectory, (b) computed phase shifts vs. measured phase shifts plotted on the line y=x (in red), (c) uncorrected and (d) corrected vector plots of the water signal for each shot (blue) and their mean (red).

METHODS

4 healthy consented subjects were scanned with a short-TE PRESS sequence on a 3T Siemens Trio scanner. Sequence parameters were TE/TR=30/3000ms, 32 averages, 20x20x20mm^3 voxel; the voxel was placed in the medial frontal lobe. One subject was scanned with water suppression OFF, to examine the effects of motion on the water phase, and 3 subjects were scanned with water suppression ON, to investigate the effects of motion on ^{1}H spectra. Subjects performed a periodic "nodding" motion during scanning while their head motion was monitored with an optical tracking system called Moire Pattern Tracking (MPT). MPT consists of a single in-bore camera and a 15x15mm^2 target which is affixed to the subject's forehead. Based on images of the target, the MPT system provides estimates of the position/orientation (**T**(t) and **R**(t)) of the head at a rate of 60 frames per second. After scanning, the MPT pose data, together with the known gradient waveform **G**(t), was used to compute motion-induced phase shifts by numerical integration of Eqs.1&2. The data acquired with water suppression ON were processed twice to produce a *corrected* spectrum and an *uncorrected* spectrum. In both cases, FID data was Fourier transformed, channels combined and frequency corrected before quantification with LCModel. In the *corrected* case, the additional step of correcting the motion-induced phases was performed before averaging.

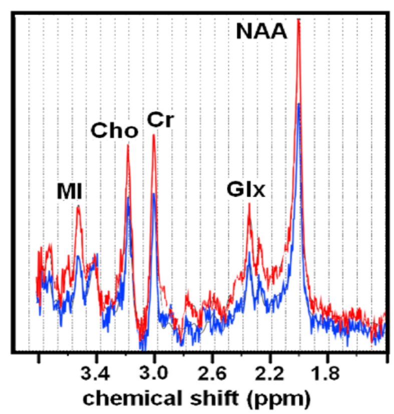

Fig. 2: Spectra processed with phase correction (red) and without (blue).

RESULTS

Figure 1 shows results from the non-water suppressed scan. Fig. 1a shows the motion trajectory during the first ¼ of the scan; the trajectory for the remainder of the scan was similar. Plotted in Fig. 1b is the predicted phase variation (as per Eq.1&2) vs. measured phase for each average. Fig. 1c and d plot the complex water signal for each average before and after removing motion-induced phase shifts; corrections reduced the phase standard deviation from 57.7° to 8.8° and increased mean signal by 63% (red arrows). Figure 2 shows representative corrected (red) and uncorrected (blue) spectra for one subject. Improved phase coherence due to motion correction improves the spectral SNR from 13 to 17; similarly, the spectral SNR of both of the other subjects (not shown) increased from 10 to 14.

DISCUSSION

We have shown that an optical motion tracking system, combined with knowledge of gradient timing, can be used to predict motion-induced phase errors and greatly reduce motion-related phase variance in single-voxel spectroscopy. The restoration of phase coherence results in improved spectral SNR. The phase correction technique demonstrated in this work can be used purely retrospectively (as here) or it could be combined with prospective motion correction to correct for residual motion and errors due to system latency.

ACKNOWLEDGEMENTS

This project was supported by NIH grants 1R01 DA021146 (TE), U54 56883 (SNRP), K02-DA16991, and G12 RR003061-21 (RCMI).

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