Correction for Magnetic Field Shift due to Mechanical Vibration in EPI Functional Imaging

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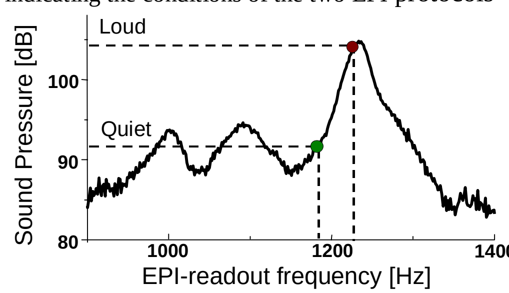
INTRODUCTION: Rapidly switched gradient fields during EPI-readout interact with the static magnetic field producing strong mechanical forces in the gradient coil system. These driving forces can stimulate natural modes of vibration in the coil system, and produce large vibrational amplitudes in on-resonance conditions [1] Vibrations can transfer heat to ferromagnetic shim elements closely attached to the gradient coil, thereby transiently reducing their magnetization and changing the homogeneity and strength of the local magnetic field. Even slight magnetic field shifts during EPI can lead to large apparent movements of the object in the phase encoding direction of EPI images. If not corrected properly, mismatches of object position in subsequent images may result in erroneous activation patterns in fMRI analyses.

METHODS: Images of a spherical water phantom (TE/TR 25/3000 ms, 4 mm slice thickness, 1 mm gap, 33 coronal slices, 48x64 matrix size, 4.1x3.1 mm in-plane resolution, 1200 time points) were acquired with two different EPI protocols: a) with a readout gradient repetition rate of 1220 Hz matching the main resonance mode of vibration of the gradient coil assembly and b) mismatching this resonance mode using a gradient repetition rate of 1160 Hz [2]. During (and after) the EPI experiment the water resonance frequency was monitored with an interleaved 1D-FID acquisition. The apparent motion artifact due to the frequency drift was quantified with retrospective image realignment. An 8 minute time series (200 timepoints) of EPI images was acquired on a human volunteer with the above off-resonance protocol described in item a). Based on a linear interpolation of the resonance frequency immediately before and after the timeseries, the apparent motion artifact in the EPI images was corrected in the time domain. The corrected *k*-space data, $S^{corr}(t)$, was obtained from the acquired data $S(t)$ by: $S^{corr}(t) = S(t)\, e^{-i \cdot \Delta\omega(t) \cdot \delta t}$ where *i*, is the position in the acquisition matrix; $\Delta\omega(t)$ is the frequency drift relative to the start of the experiment, and δt is the time interval between two consecutive phase encoding blips. Maps of spurious activation and deactivation patterns were calculated by statistical analysis of the corrected and uncorrected images using a general linear model with a block design, arbitrarily chosen with four blocks (1 min stimulation, 1 min rest). Clusters with at least 10 voxels (500 mm^3) and below a threshold of p=0.05 were considered significant. Activation patterns were overlaid on the subject's T1 weighted image.

RESULTS: The frequency drift measured in phantom experiments was found to be about five times larger during the on-resonance (loud) EPI protocol than for the off-resonance protocol (quiet). For both, the frequency increases exponentially during EPI and afterwards exponentially decays to its initial value (see Fig.2). The frequency drift proved to be sufficiently slow to be linearly approximated during a typical 8 minute fMRI timeseries acquired from a human volunteer (see Fig. 3). Activation maps obtained from uncorrected (Fig 4a) and corrected images (Fig. 4b) show that the proposed frequency drift correction significantly reduces spurious activation.

CONCLUSIONS: Care should be taken to choose imaging parameters to not stimulate natural vibration modes of the gradient coil system in order to keep vibration low and avoid system instabilities that can produce apparent motion artifacts in EPI. Remaining artifacts can easily be corrected by providing knowledge of the magnetic field drift. Since this drift is usually slow compared to the length of typical EPI timeseries (~10 minutes), a phase correction method based on linear interpolation between two measurements of the resonant frequency (immediately before and after the EPI timeseries) demonstrated to correct the apparent motion and spurious activation artifacts.

Fig 1: The vibrational resonance of the z-gradient coil, indicating the conditions of the two EPI protocols



REFERENCE:

1 Tomasi et al (2003). Magn Reson Imaging **18**:128–130.

2 Tomasi et al (2003) Human Brain Mapping Annual Meeting, June 13-17, 2004, Budapest, Hungary

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Fig 4: Activation maps for a) uncorrected, b) frequency drift corrected time series. Orange (green) voxels show positive (negative) correlation with the statistical model. a) Large spurious activation clusters marked by blue arrows [p<0.0005 (orange) and 0.003 (green)] due to apparent motion. The most significant activation in b is located at the left frontal cortex (arrow; p = 0.025).

Fig 2: Frequency drift during EPI acquisition [gray block] with the two protocols and subsequent recovery time [white block] in phantom experiments.

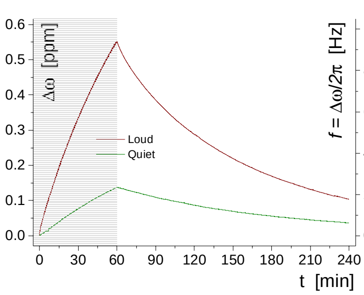

Fig 3: Frequency drift during *in vivo* EPI (solid) and linear interpolation (dotted) between endpoints