In fMRI a Dual Echo Time EPI Pulse Sequence can Induce Sources of Error in Dynamic Magnetic Field Maps

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Introduction: Many techniques to correct geometric distortion artifacts common in echo planar imaging (EPI) used in functional MRI (fMRI) experimentation require estimation of the main magnetic field (B_0) offset. One such method uses the phase difference between two EPI images acquired at two different times with two different echo times to determine this offset [1]. From here on, this method will be referred to as dual echo time EPI. In general, the static field is estimated once at the beginning of a time series acquisition and used to correct each subsequent image [1]. Alternatively, the method can be used to estimate and correct the dynamic field at every time point, the potential utility of which has been evaluated to some degree [2]. Although the method can be very robust, its validity is predicated on consistency of the magnetic field during the acquisition of the two images used for estimation and correction. Any change in the value of B_0 between acquisitions of the images leads to errors in the estimated maps. In addition, because the two images are acquired following separate RF excitations, inconsistencies in these pulses will also induce errors in the estimated maps. Investigation of these potential errors is possible through simultaneous use of dual echo time EPI and a Moving RaceTrack Trajectory (MRTT) acquisition [3]. In MRTT, both images needed to estimate the field are acquired after a single RF pulse in an interleaved fashion. As a result, the MRTT maps are immune to the type of errors just described, providing a valid basis for comparison.

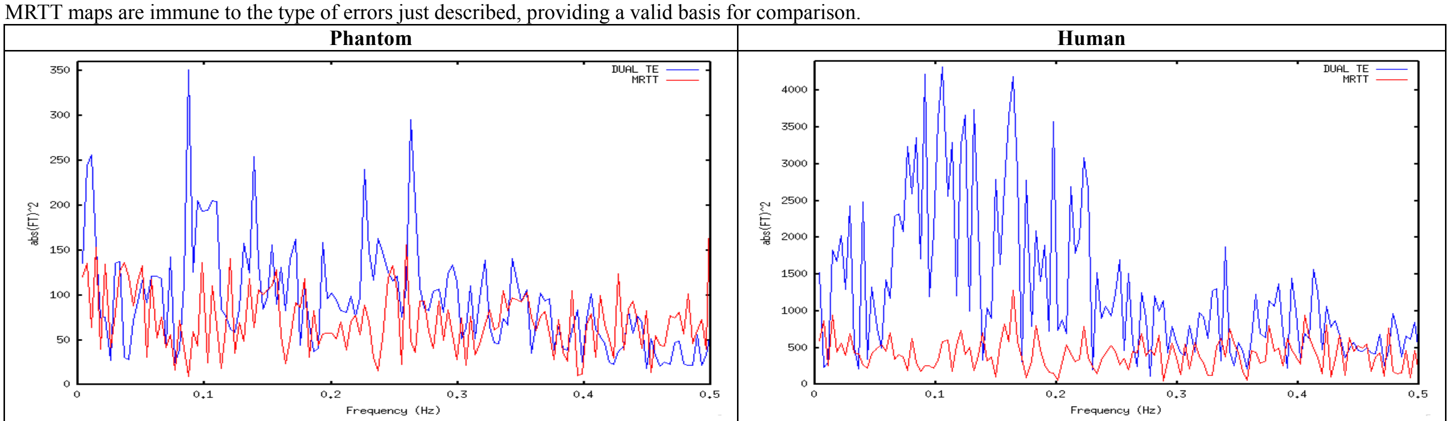

Figure 1. Average power spectrum of voxel time series in a 5×5 voxel region for phantom and human.

Methods: Experiments were performed on a GE Signa LX 3T MRI scanner (General Electric, Milwaukee, WI) using a custom pulse sequence, which provided two separate methods of for calculation of a B_0 field offset map. First, each repetition in the series acquisition used a MRTT at full resolution where each k-space line is acquired twice, with a time ΔTE_m = 1.872 ms between the two passes (matrix size = 64×64, FOV = 24 cm, slice thickness = 3.8 mm, TE = 44.3 ms, TR = 1 s, flip angle = 45°, repetitions = 276). Second, TE was increased by ΔTE_m for odd repetitions in the series, enabling estimation of B_0 with the dual echo time method described above. The raw field maps were fit with a 7^{th} order polynomial before being compared to reduce noise. Because ΔTE is the same for the two sets of estimated field maps, the SNR in each should be equal, allowing for a fair comparison between the two. Experiments were performed with both a phantom and with a human subject. The main field should be nearly time invariant when imaging the phantom (no motion or physiologic phenomena) and any significant differences in the two sets of maps would most likely result from hardware instability, specifically related to the RF pulses. In the human experiment, the presence of temporal fluctuations in B_0 could induce additional differences in the two sets of estimated field maps.

Results: The average power spectrum from a 5×5 voxel region in the estimated field maps from both the phantom and human experiments are shown in Figure 1. In the phantom, there appears to be some discrepancy between the two spectra at certain frequencies. This indicates potential inconsistencies in the RF phase or fluctuations in the main field resulting from some scanner based instability, as most other sources of error should have similar effect on each method. In the human data, larger discrepancies are apparent. Certain (most) frequencies are amplified in the dual TE map power spectrum, especially at lower frequencies, which includes the respiratory frequency and heart rate could potentially be aliased to the low frequencies as well. To further demonstrate the increased error in the human data, a paired-difference t-test was performed on the two sets of maps in both the phantom and human data, and maps of the computed t-statistics are shown in Figure 2. The low t-statistics in the phantom case indicate that the mean of the pair-wise difference of these field maps does not stray significantly from zero. This strongly indicates that the differences in the power spectrum arise from regular, periodic phenomena that average to zero, as might be caused by a slowly oscillating RF phase through time. However, human results show significant differences in the pair-wise mean of the maps, further exemplifying the presence of irregular sources of error exist in this case.

Discussion: Subject motion can cause dramatic changes in the homogeneity of the main magnetic field, and dependence of the B_0 off-resonance on respiration has been demonstrated as well [4]. These and other sources of field variation appear to have detrimental effects on dual echo EPI field maps. These results emphasize that care must be taken to minimize the chances of magnetic field changes between acquisition of the two images. Precautions might include a simple breath hold, or shortening the time between acquisitions of the two images as much as possible. Hardware inconsistencies are harder to eliminate in general, however, these effects appear be small with respect to physiological sources of error. While a single high quality map may be acquired with relative ease through multiple averages, using the dual echo time method to acquire many maps through time, such as might be desirable in fMRI, does not seem feasible with this method. Using a very short repetition time sacrifices SNR or changes T_1 weighting, or both, breathing is unavoidable and hardware inconsistency is common. This method performs well in a static field, but errors become non-negligible in the presence of dynamic field components.

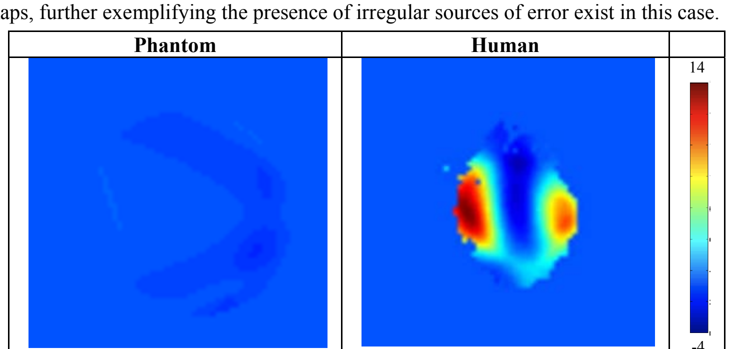

Figure 2. Maps of t-statistics from a paired-difference test between field maps estimated using MRTT and the dual echo time methods.

References: **1.** PJ Reber et al., MRM 39:328-330, 1998. **2.** C Hutton et al., NIMG 16:217-240, 2002. **3.** V Roopchansingh et al., MRM 50:839-843, 2003. **4.** PF Van de Moortele et al.: MRM 47:888-895, 2002.

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