Dynamic Magnetic Field Corrections Improve Phase-Only fMRI Activations

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Introduction: In MRI time series, specifically in functional MRI (fMRI), most statistical analysis is performed on only the magnitude signal component. This is largely because the blood oxygenation level dependent (BOLD) signal [1] is manifested in the magnitude, but also because the phase signal can be difficult to analyze due to its strong sensitivity to changes in the main magnetic field. It has been repeatedly shown that respiration has a strong effect on the phase signal [2,3] and also that motion inside or outside the field of view can severely alter the phase signal [3]. However, valuable biological information could potentially be found in the phase. Functional task related phase changes may help identify draining veins [4], and magnetic transients resulting from neuronal action potentials may be detectible with use of the phase signal [5]. However, recent work has thoroughly outlined various sources of phase instability, resulting in reduced statistical power and specificity [6]. It was recently shown that a method for dynamic estimation of the changes in the magnetic field leading to undesirable phase changes and subsequent correction drastically improves the utility of a complex fMRI activation model which assumes constant temporal phase, thus often termed the complex constant-phase method [7]. In this case the dynamic field corrections stabilized the phase, providing the then expected increased detection power the model provides. It follows that the same type of field corrections will be useful when directly modeling phase, which is the topic of the following investigation. Specifically, the utility of the dynamic field correction process in detecting task related phase changes is shown.

Methods: An fMRI experiment was performed on a single subject on a 3T MRI scanner (General Electric, Milwaukee, WI). A bilateral finger-tapping task was performed with a visual cue indicating whether to tap or rest. The paradigm followed a block design with and initial 20 s rest followed by 10 epochs of 8 s on and 8 s off. An echo planar (EPI) pulse sequence (TE=26 ms, BW=250 Hz, matrix = 64×64, FOV=24 cm, slice thickness=3.8 mm, #slices=9, TR=1 s, repetitions=180) was used. The resulting phase time series was analyzed using a general linear model (GLM) with 3 reference functions corresponding to a constant and linear trend in addition to a square waveform which was either -1 or 1 corresponding to periods of rest or task respectively. The phase was mean centered in each voxel and although it was not needed within the brain, phase was unwrapped before performing the regression. This analysis was applied with and without the dynamic field corrections, the specific methods of which are described in [3]. Also of note, each field map was fit with a 4^{th} order 2D polynomial in order to preserve local phase changes occurring on a higher than 4^{th} order spatial scale.

Results: Figure 1 shows a single acquired slice overlaid by the phase-activation t-statistics that resulted from the GLM regression described above. The statistics in the images of Figure 1 are shown above an unadjusted threshold of $p<.0012$ ($t>= 3.285$). In the absence of the dynamic correction (Figure 1a), no task related activation is seen in the motor cortex where activation is expected, however, a large region of negative activation is present in the anterior of the brain where we would not expect to see task related phase activation for this experiment. This non-localized region of above threshold voxels is likely due to task related motion or some similar undesirable (non-target) modulation of the field related to the task. The phase activation pattern in the image depicted in Figure 1b presents a stark contrast to that in Figure 1a. When the dynamic correction precedes the statistical analysis, the results resemble a pattern that might be expected from the experimental stimulation. Figure 2 shows plots of the phase signal (2a and 2b) along with the corresponding frequency spectrum (2c) from a representative voxel. The uncorrected phase signal appears very noisy, and it has many spectral components that increase residual variance and prevent detection of statistically significant activation at the task frequency of .0625 Hz ($t=1.51$, $p=.133$). The corrected signal in Figure 2b and 2c has much less variability and the task frequency becomes apparent by visual inspection. Figure 2c shows that nearly all unwanted signal components have been removed, leaving behind a nearly flat (white) spectrum. Importantly, the task related signal changes are preserved after the correction, demonstrated by the remaining peak near .0625 Hz, which now has twice the amplitude of the next highest peak. This is further represented in the new, significant, activation t-statistic ($t=5.07$, $p=1\times10^{-6}$). Although the correction does appear to undesirably dampen the .0625 Hz peak, the linear trend present in the uncorrected signal (see Figure 2a) is characterized by a 1/f frequency distribution, clearly visible in Figure 2c, which elevates the low frequency components. This is removed by correction (see Figure 2b) giving the false impression that task related phase changes were being removed by the correction.

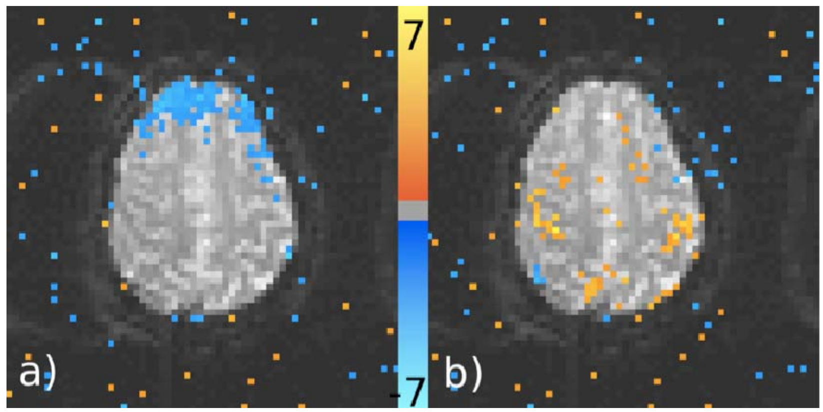
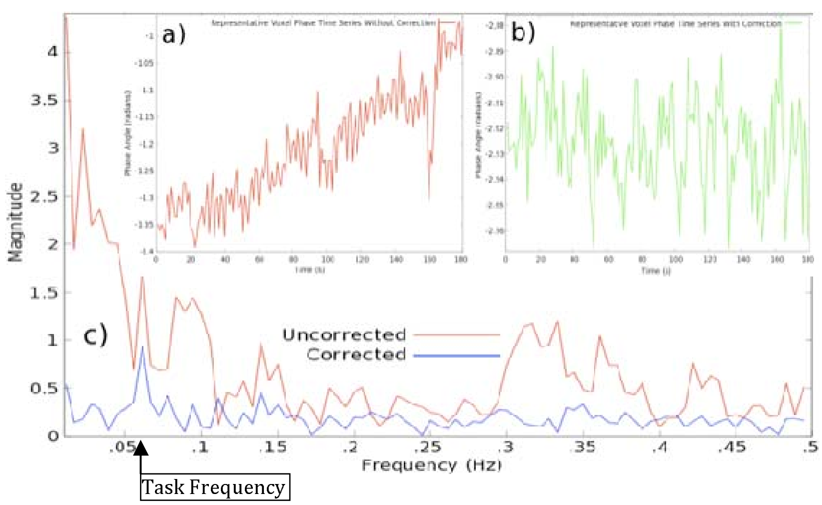


Figure 1 (above). Phase-activation t-statistic (unadjusted threshold of $p<.0012$) maps in a single slice before (a) and after (b) dynamic magnetic field correction.

Figure 2 (below). Plots of phase time series in a single representative voxel before (a) and after (b) correction. Frequency spectra of the signals from in (a) and (b) are plotted together in (c).



Discussion: The phase stabilizing capabilities of the dynamic correction demonstrated here corroborate previous results reporting similar activation recovery using the dynamic correction in conjunction with a complex valued activation model [3,7]. While further investigation is required and ongoing, current evidence engenders optimism that dynamic magnetic field correction can provide a significant step toward reliable phase stability and the ability to investigate meaningful components of the signal otherwise unattainable.

References: **1.** S Ogawa et al.: PNAS USA 87:9868-9872, 1990. **2.** PF Van de Moortele et al.: MRM 47:888-895, 2002. **3.** AD Hahn et al.: NIMG doi:10.1016/j.neuroimage.2008.10.001, 2008. **4.** AS Nencka, DB Rowe: NIMG 37:177-188, 2007. **5.** J Bodurka et al.: JMR 137:265-271, 1999. **6.** GE Hagberget al.: MRI 26:1026-1040, 2008. **7.** DB Rowe, BR Logan: NIMG 23:1078-1092, 2004. **Acknowledgements:** Funded in part by EB000215 and EB007827.