Phase Regression and Dynamic B-Field Correction Reduce Global Time Series Correlations and Increase Functional Correlations

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Introduction: Functional connectivity magnetic resonance imaging (fcMRI) [1] has become an integral tool of neuroscience research. This abstract seeks to improve the data quality associated with fcMRI. fcMRI relies upon restating state data and is theoretically preferred over functional magnetic resonance imaging (fMRI) in clinical populations as it does not require patients to comply with functional tasks. However, the fcMRI signal of interest is significantly smaller than the task-related signal of interest in fMRI. Thus, the fcMRI signal may be obscured by other confounding signals. Much work has been performed to reduce such nuisance contributions through temporal filtering, global signal regression, white matter signal regression, cerebrospinalfluid signal regression, and physiologic signal regression including respiratory and cardiac signal regression [2,3,4]. Subject motion can also confound the fcMRI signal. Motion leads to voxel volume composition changes, and varying magnetic field inhomogeneities. Such inhomogeneities cause image warping and expedited signal decay. This abstract considers two methods for removing such magnetic field effects from fcMRI data using the phase regressor method [5], and a dynamic B-field estimation and correction method [6].

Methods: The phase regressor method relies upon the relationship between the phase of the reconstructed image and the magnetic field inhomogeneity. The reconstructed image may be considered as $img(x,y)=\rho(x,y)\exp(-TE/T_2^*(x,y)+i\Delta B(x,y)TE\gamma/2\pi)$, where *img(x,y)* is the reconstructed image at the point *(x,y)*, $\rho(x,y)$ is the proton spin density at the point *(x,y)*, *TE* is the echo time, $T_2^*(x,y)$ is the intra-acquisition decay rate at the point *(x,y)*, γ is the gyromagnetic ratio of the proton, and $\Delta B(x,y)$ is the magnetic field inhomogeneity at the point *(x,y)*. It is clear from this that the phase from the reconstructed image is $\Delta B(x,y)TE\gamma/(2\pi)$. Thus, phase changes in the image time series are associated with magnetic field changes. The phase regressor method assumes that image magnitude changes that are associated with magnetic field changes are linearly dependent upon image phase changes. Thus, for each voxel time series, the magnitude is regressed as a linear function of phase, and an estimated magnitude is removed from each time point's magnitude observation based upon the phase observation. Thus, magnitude changes associated with magnetic field changes are regressed from the data. The implemented method assumes no error in the phase as the magnitude noise dominates.

The dynamic magnetic field estimation and correction method estimates the deviation of the magnetic field at each time point from the average magnetic field of the time series acquisition by measuring the phase difference between the two. The method then utilizes the time segmented magnetic field correction scheme [7]. Here, each phase encoding line of the echo planar imaging acquisition is a time segment.

Results: Experimental data was acquired on a General Electric 3.0 T system with a standard echo planar pulse sequence. Complex-valued data were reconstructed off line with custom software, utilizing three navigator echoes to correct the Nyquist ghost [8]. Scan parameters included: 64×64 matrix, 24×24 cm^2 field of view, 9 slices, 3 mm slice thickness, 1 mm inter-slice gap, 125 kHz acquisition bandwidth, 26.0 ms echo time, 1000.0 ms repetition time, 45^o flip angle, and 460 repetitions. The subject was at rest for the first 230 repetitions, and was visually cued to perform a block designed, bilateral finger tapping task for the final 230 repetitions. Functional regions of interest in the left and right motor cortices, as well as in the functionally unconnected parietal lobe were defined using the final 230 repetitions. The data set was then truncated to the first 230 repetitions for the resting state analysis. Data was considered in 6 separate cases: no processing, motion correction (MC), phase regression (PR), dynamic B-field correction (Dyn. B), phase regression and image registration (PR+MC), dynamic B-field correction and image registration (Dyn. B + MC). The correlation between regions of interest in the functionally connected right motor cortex (RM) and left motor cortex (LM) as well as functionally unconnected parietal lobe gray matter (PL) were calculated and are shown in Table 1.

Table 1:	No Processing	MC	PR	PR+MC	Dyn. B	Dyn. B + MC
LM-RM	0.3773	0.3977	0.5632	0.5077	0.4222	0.4494
LM-PL	0.1678	0.2435	0.1372	0.2344	0.1053	0.1647
RM-PL	-0.3493	-0.2484	-0.2320	-0.1574	-0.3804	0.1078

Discussion: It is clear that the phase regressor method and the dynamic B-field correction method perform differently in the experimental conditions. The phase regressor method yields increased correlation measurements between regions which are expected to be correlated and decreased correlation measurements between regions which are not expected to be correlated. Thus, its performance in the considered data set yields favorable results. In spite of the numerical differences noted in the table, only minor differences are apparent between the motion correction and phase regressor and motion correction maps of the correlation coefficients as seen in Figure 1. Figure 1a illustrates the regions of interest used for Table 1. Figures 1b, 1c, and 1d illustrate the regions which display high correlations with the region of interest in the left (top) motor cortex after motion correction, phase regression and motion correction, and dynamic B-field correction and motion correction, respectively. The phase regression method minorly alters the connectivity map, including slightly increased correlation coefficients in the connected regions, and increased area of connected cortex. The dynamic B-field correction yields increased correlation coefficients over a smaller area of connectivity. This preliminary study suggests that phase regression and dynamic B-field correction yield improved functional connectivity data by reducing correlation coefficients between unconnected regions and increasing correlation coefficients between connected regions. As the dynamic B-field correction method does not rely upon an emperical fit of magnitude as a function of phase, but depends upon a physical model for the estimation and correction for magnetic field inhomogenities, it is theoretically preferred although a reduced area of connectivity is observed.

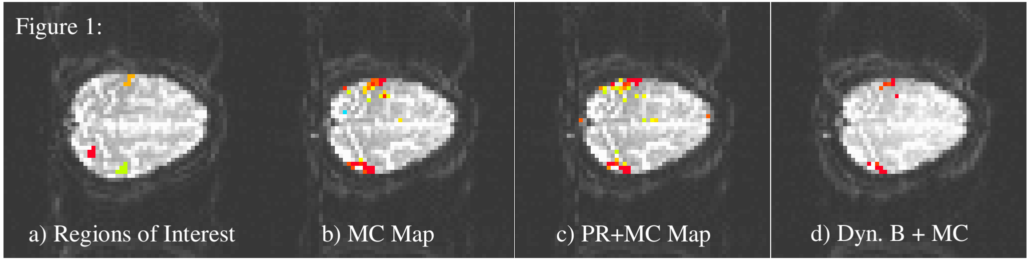
Figure 1:
a) Regions of Interest
b) MC Map
c) PR+MC Map
d) Dyn. B + MC

References: [1] Biswal, et al. 1995 MRM 34:537; [2] Glover, et al. 2000 MRM 44:162; [3] Birn, et al. 2006 NIMG 31:1536; [4] Shmueli, et al. 2007 NIMG 38:306; [5] Menon 2002 MRM 47:1; [6] Hahn, et al. 2008 NIMG: In Press; [7] Noll, et al. 1991 IEEE TMI 10:629; [8] Nencka, et al. 2008 Proc. 16th ISMRM:3032. **Support:** Funded in part by NIH EB00215, MH019992.