CSF Signal as a Complex-Valued RETROICOR Regressor Removes Unwanted Physiological Signal and Increases the Accuracy of Spatial Correlation in Complex-Valued fMRI

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Synopsis

Discarding the phase component of the time-series removes relevant biological information from a complex-valued signal. Although, commonly implemented retrospective image correction techniques fail to account for physiological artifacts in both the magnitude and phase components of the time-series. Using the CSF signal, observed during the data acquisition, as a complex-valued regressor increases the statistical power of fMRI analysis, through reducing unwanted physiological variability in the complex-valued signal of interest. The improved performance of implementing the complex-valued image correction methods is demonstrated with a comparison of magnitude-only and complex-valued spatial correlations.

Purpose & Background

In an fMRI time-series, CSF signal fluctuations independent of the task-activated BOLD signal are inherent within spatial frequency measurements [1]. Retrospective image correction (RETROICOR) regression methods substantially reduce undesirable physiological variability in the time-series [2]. Although in RETROICOR methods, only the magnitude component of the time-series is considered, despite evidence of task related change observed in the phase time-series [3]. Discarding the phase or neglecting to account for the unwanted physiological signal within the phase decreases the statistical computing power of the model. This study demonstrates the advantage of using a complex–valued CSF signal, estimated from an axial slice inferior to the slice of interest, as a complex RETROICOR regressor in complex-valued fMRI data. Implementing complex RETROICOR regressors reduce nuisance signals and more accurately estimates spatial correlations. The metric for showing the increased performance is a comparison of magnitude-only (MO) and complex-valued (CV) spatial correlations.

Methods

Experimental human fMRI data is collected with a single subject on a 3.0 T scanner from a bilateral finger tapping experiment, performed for sixteen 22-second periods, with an echo planar pulse sequence (TR/TE =1000/39 ms, BW = 125 kHz, 4 mm thick axial slices, matrix = 96×96, no. of slices = 10, FOV = 24.0 cm, flip angle = 45°, repetitions = 720). The k-space readout was Nyquist ghost corrected, IFT reconstructed, and TOAST dynamic B0 corrected [4]. The complex-valued CSF signal is estimated from isolating the ventricles of an inferior axial slice, and measuring the mean CV signal. The magnitude and phase regression coefficients, $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ are computed with a slice corresponding to the task-activated motor cortices, with a complex-valued regression model [5]. The magnitude and phase components originating from the CSF signal are removed from the task-activated slice of interest from a MO and CV time-series separately, and the data is spatially smoothed with a Gaussian kernel with a full-width-half-max of 3 voxels. The MO and CV spatial correlations in terms of their temporal frequencies [6] before and after the CSF regression, are compared for two seed voxels: *a* which is located in the white matter, and *b* which is located in the region superior to the ventricles.

Results & Discussion

The seed voxels, *a* and *b*, in Fig. 1A show significant global correlations in the magnitude. Comparing Fig. 1A to Fig. 1B, the MO and CV spatial correlations before CSF regression both exhibit global correlations, with noticeable overall phase distortions within the complex-valued data. Discarding the

phase component prematurely eliminates valuable biological information, which will be appropriately removed in the complex-valued regression if the phase component consists of extraneous signal. Fig. 1C shows improvement of the spatial correlation maps in the magnitude after CSF regression, compared to Fig. 1A. Comparing Fig. 1C to Fig. 1D, demonstrates the performance of the complex-valued CSF signal as a RETRIOCOR regressor. The CV spatial correlations show a more significant reduction in physiological variability in the data from including the CSF phase component in the regression. The complex regressor is robust enough to significantly remove unwanted physiological signal, and improve spatial correlation maps in comparison of the CV to the MO spatial correlations. Only removing the physiological noise in the magnitude component of the time-series will result in CV correlation maps in Fig. 1D to be identical to Fig. 1C.

Conclusion

While the results show improvement implementing the magnitude-only regression, a striking decrease in variability is notable with the complex regression. Using the CSF signal as a complex-valued regressor in retrospective correction decreases physiological noise and increases the accuracy of spatial correlations in complex-valued fMRI. Failing to account for physiological artifacts in the magnitude and phase components of the time-series in fMRI data results in an overestimation of spatial correlations.

Acknowledgements

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References

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Figures

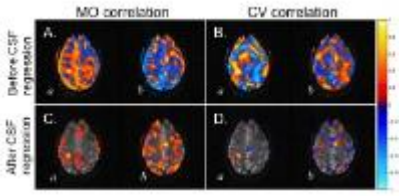

Figure 1: Spatial correlation maps for two seed voxels, a and b, showing (A) MO correlation and (B) CV correlation before CSF regression, and (C) MO correlation and (D) CV correlation after CSF regression.