Component Based Noise Correction for Perfusion fMRI

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Introduction

Perfusion based functional magnetic resonance (fMRI) utilizing arterial spin labeling (ASL) techniques has several potential advantages over traditional blood oxygenation level dependent (BOLD) based imaging, such as 1) better localization of neural activity and 2) potentially less inter-subject variability [1][2]. However, the ASL signal exhibits low signal-to-noise and is often confounded by physiological noise sources [3]. Several post-processing algorithms have been developed for the removal of physiological noise components in BOLD data and include retrospective image correction (RETROICOR), k-space based correction (RETROKCOR), and component based analysis [3,4,5,8]. In a previous study, a modified version of RETROICOR (mRETROICOR) was shown to improve the sensitivity of ASL data [3]. However, mRETROICOR requires external monitoring of physiological data and although it has been shown to significantly increase sensitivity its use has been limited. Component based algorithms require no external monitoring and have been shown to significantly improve BOLD sensitivity [5]. Here we extend a component-based algorithm (CompCor) for use in perfusion fMRI and characterize the identified components by comparison to mRETROICOR.

Theory

Component based noise correction techniques in BOLD imaging utilize the spatial coherence of noise components to estimate and subsequently remove components identified as noise[5,8]. However in ASL there is increased difficulty in characterizing the identified components due to aliasing of cardiac and respiratory components caused by the limited temporal resolution of ASL techniques. Additionally, the interleaving of tag and control images and the formation of a perfusion time-series by temporal differencing may complicate the identification of structured noise elements. Application of mRETROICOR seems to suggest that the structure is preserved in the perfusion time series [3], and consequently the CompCor approach begins by first analyzing the perfusion time-series data y, formed by a surround subtraction of control and tag images, with a general linear model (GLM) of the form y=BXh+Sb+n, where B is the basis set for defining the hemodynamic function, X is the design matrix related to the stimulus paradigm, S is the matrix containing linear and constant nuisance parameters, n is a matrix of residuals, and h and b are the respective weights of the stimulus response and nuisance terms [6]. We can estimate h and b in a standard general least-squares approximation and calculate the residuals as y-BXh+Sb. The structured noise components are then estimated with the use of a principal component analysis of the residuals [5,8]. The first two components are then reintroduced as nuisance parameters in S, and h and b are recalculated.

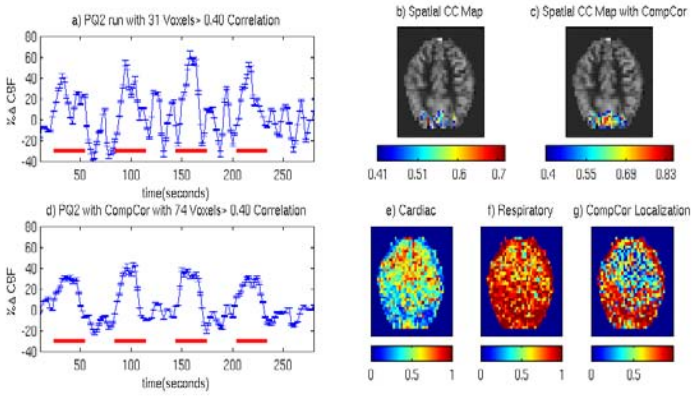
Methods

Experimental Protocol: A visual stimulation study was performed on 3 subjects with the use of a black and white radial checkerboard flashing at 8 Hz presented in a block design paradigm consisting of 4 cycles of 20s stimulation with 40s rest. Scanning was performed on a 3T GE Signa whole body system, with a body transmit coil and an 8 channel receive only head coil. A PICORE QUIPSS II [7] sequence was used with a dual gradient echo spiral readout. Imaging parameters for the visual stimulus were: TR=2s, TI1=600ms, TI2=1500ms, $\theta = 90°$, FOV = 24×24 cm2, matrix size 64×64, TE1=9.1ms, TE2=30ms, with four 7mm slices positioned through the primary visual cortex at an oblique angle parallel to the calcarine sulcus. The tagging band was 100 mm thick, positioned 10mm from the proximal edge of the first slice. A small diffusion pulse (b-factor=2) was also used. Cardiac pulse and respiratory effort data were recorded with a sampling rate of 40 samples/sec.

Image processing: Images from each subject were co-registered for motion correction. Perfusion (CBF) time series were formed from the running subtraction of the ASL data derived from the first echo. Cardiac and respiratory confounds were removed from the data using the mRETROICOR method described in [3]. CompCor was also applied to the data to remove spatially coherent noise elements. Correlation coefficients were calculated using a reference function consisting of the stimulus pattern convolved with a gamma density function with the inclusion of constant and linear trends. The number of voxels, with and without the application of CompCor, exceeding a correlation threshold of 0.4 was tabulated within the defined visual cortex ROI. Significance values and contrast-to-noise ratio (CNR) were also computed across combinations of conditions. Paired t-tests were used to compare calculated correlation coefficients (CC) and p-values between corrected and uncorrected data within a functional ROI defined by the union of the thresholded correlation maps. Additionally, mRETROICOR and CompCor algorithms were compared by a voxel-wise correlation analysis of identified noise components.

Results

Figure 1a) and 1d) show the average time series over a given slice for a representative subject with and without application of CompCor, respectively. In addition to the noticeably marked increase in CNR of the average time-series, the number of voxels surpassing the correlation threshold of 0.4 increased from 31 to 74 with the application of CompCor. Additionally, paired t-tests performed between CC and p-values between corrected and uncorrected data showed significant improvement in all subjects. Comparison of mRETROICOR and CompCor did not reveal a significant difference in the voxel-wise p-values. Spatial maps of the calculated correlation coefficients (CC) above the defined threshold are presented in panels b) and c) and overlaid on their average perfusion maps. It is important to note CompCor corrected data has increased spatial coverage that is localized to gray matter. Panel g) is a correlation map between the estimated noise removed by CompCor and that estimated with mRETROICOR. Panels e) and f) show the estimated fraction of cardiac and respiratory noise variance to the overall removed noise variance as estimated by mRETROICOR. In comparing panels f) and g), CompCor components appear to correspond to the estimated respiratory noise components.



Discussion

CompCor, through the reduction of noise, increases sensitivity and spatial coverage in perfusion based fMRI. The performance of CompCor in increasing sensitivity is comparable to mRETROICOR but requires no external monitoring and is not dependent on obtaining good quality physiological data. CompCor appears to remove physiological noise associated with respiratory effects. This is expected since respiratory induced noise has been shown to be global in nature [4], and CompCor is sensitive to spatially coherent noise elements. Future extensions of CompCor would benefit from region specific component analysis to identify and remove spatially localized cardiac noise.

References

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