High spatial and temporal resolution fcMRI with BOLD selectivity using multiecho simultaneous multislice EPI

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Introduction

Resting-state functional connectivity magnetic resonance imaging (fcMRI) has emerged as a key approach for characterizing the functional connectivity of the human brain. One of the key factors limiting the sensitivity of fcMRI measures is the presence of non-neural confounds, such as motion and physiological noise. These confounds can be partially reduced by post-processing methods, such as retrospective noise correction [1], but these methods can underestimate the effects of noise confounds and often require the acquisition of additional physiological measures. Recent work has shown that the acquisition of multiple echoes can enable the automated identification and robust removal of physiological noise confounds without the need for external measures of physiological activity [2]. However, the extra readout time required for the acquisition of multiple echoes leads to a decrease in temporal resolution (i.e. higher TR), as compared to more standard single echo acquisitions. In this study, we used both in-plane acceleration and a simultaneous multislice excitation strategy to compensate for the extra readout time and achieve whole brain coverage with 3 echoes, 2 mm isotropic resolution, and a TR of 2 seconds. We compared the performance of the multiecho simultaneous multislice (MESMS) acquisition with that of a single-echo simultaneous multislice (SESMS) acquisition with the same spatial resolution and higher temporal resolution (TR = 1.25s).

Methods

fMRI resting state data were collected from a single subject on a 3T GE MR750 system with a 32 channel receive coil (Nova Medical). Resting-state scans (5 minute duration each; eyes closed) were performed using SESMS and MESMS (3 echoes) echoplanar imaging (EPI) acquisitions, where both acquisitions used 2.5-fold phase encode undersampling and achieved 2mm isotropic resolution with whole brain coverage (FOV 20cm, 100x100 matrix, 72 slices). We used the blipped-CAIPI EPI k-space trajectory with 3 sagittal slices per RF excitation [3]. Other parameters were SESMS: TR=1.25s (240 volumes), TE = 30ms; MESMS: TR=2s (150 volumes) and TEs =15.5ms, 36.7ms and 57.9ms. To estimate the coil sensitivities, we collected a single-echo single-slice (SESS) dataset. We used SENSE reconstruction with a fast Conjugate Gradient Toeplitz-based iterative algorithm regularized with a spatial roughness penalty [4]. To maintain comparable smoothness in the SESMS and MESMS acquisitions, we used a local point-spread function (PSF) analysis to set the regularization term, such that the FWHM of the PSF was 1.2 voxels [5]. Following the approach of [2], the multiple echo data from the MESMS scan were spatially concatenated and decomposed using spatial independent components analysis [6]. The weights of each component were then fit to a BOLD signal model and a goodness of fit metric was used to automatically differentiate BOLD components from non-BOLD components. The time series from the multiple echoes were optimally combined using the approach of [7] to form a single time series for each voxel. These time series were then denoised by regressing out the contributions of the non-BOLD ICA components. For the SESMS data, we used high resolution anatomical images to identify regions of white matter (WM) and cerebral spinal fluid (CSF), with partial volume threshold of 0.99 for each tissue type. Denoising of the SESMS data was achieved by regressing out the contributions of the average WM and CSF signals [8]. To generate functional connectivity maps, a seed signal from the posterior cingulate cortex (PCC) was computed and correlated with every other voxel in the brain [8]. To examine the effects of filtering, we applied a lowpass filter (fc = 0.08Hz) to both the denoised MESMS and SESMS datasets and recomputed the functional connectivity maps.

Results and Discussion

Figure 1 shows functional connectivity maps obtained from the denoised SESMS and MESMS data both prior to (top row) and after low pass filtering (bottom row). The maps obtained with MESMS show greater spatial specificity as compared to the SESMS maps. The spatial patterns in the MESMS maps are largely unaffected by the application of lowpass filtering, indicating that the multiecho denoising process has successfully removed both low-frequency and high-frequency non-BOLD noise components. In contrast, low pass filtering significantly improves the spatial specificity of the SESMS maps, indicating that the WM+CSF denoising approach has not identified some high frequency noise components. Our findings suggest that the denoising advantage gained through the acquisition of multiple echoes outweighs the performance gains of obtaining greater degrees of freedom (i.e. more images per scan at a shorter TR) achievable with a single echo acquisition. The integration of the multiecho and simultaneous multislice capabilities enables the multiecho data to be acquired with both high spatial and temporal resolution.

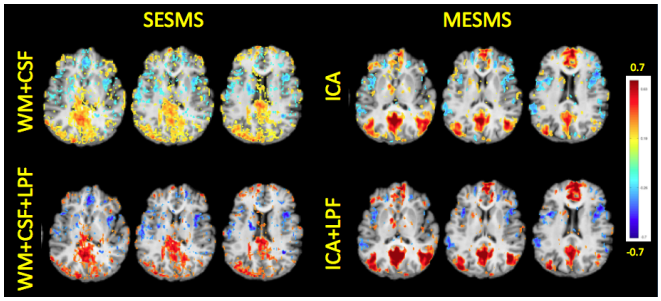

Figure 1. Functional connectivity maps obtained using a seed signal from the posterior cingulate cortex. Correlation values are thresholded at p = 0.05, with correction for degrees of freedom.

References: [1] Chang and Glover; *NIMG 47:*1448, 2009. [2] Kundu et al, OHBM 2011, p. 683. [3] Setsompop et al, MRM 2011; [4] Fessler et al, IEEE TSP, 53:3393, 2005. [5] Fessler and Rogers, IEEE TIP, 5:1346, 1996 [6] Beckmann & Smith, IEEE TMI, 23:137, 2004. [7] Posse et al, MRM, 42:87, 1999. [8] Van Dijk et al, J Neurophys, 103:207, 2010.