Denoising of Sub-Millimeter Event-Related fMRI at 3T for Robust Detection of BOLD Contrast

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Introduction

Functional magnetic resonance imaging (fMRI) is typically performed at a low spatial resolution (e.g. 3x3x3.125 mm^3) in order to achieve a blood oxygenation level dependent (BOLD) contrast-to-noise ratio (CNR) sufficient for robust detection of activation. The functional unit of the brain is a columnar collection of neurons and a vascular capillary bed that spans the cortical thickness of about 2-3 millimeters and is under a millimeter in diameter [1]. Each voxel in a low-resolution fMRI study therefore contains multiple functional units. This means that the maximum ratio of BOLD contrast to voxel volume in a single voxel is potentially limited by partial volume effects [2]. To maximize the BOLD contrast to voxel volume, the dimensions of the imaging voxel should be matched to those of the functional unit. However, as resolution increases, the signal-to-noise ratio (SNR) of the data decreases, potentially making detection of BOLD contrast more difficult. This study reports on the dependence of the SNR and CNR for event-related visual stimulus fMRI as a function of in-plane spatial resolution. The CNR and detection performance are considered with and without application of a denoising algorithm [3]. Sub-millimeter in-plane resolution is achieved using a small field of view (FOV) and a surface coil.

Methods

Functional MRI (TR/TE=500/35.5 ms, 50° flip angle, 1 slice/volume, 3 mm slice thickness, 1230 volumes, 12 cm FOV) was performed using a 3T whole-body MR scanner (GE Healthcare) and a seven-inch diameter surface coil positioned over the visual cortex of a healthy normal volunteer. An MR-compatible synchronization control system (MRIx Technologies, Bannockburn, IL) was used to present two seconds of a flashing (10 Hz) left hemifield every 15 seconds. The volunteer was instructed to fixate on a white crosshair located in the center of the stimulus for the entire paradigm and to press a button switch at the start of each stimulus so that reaction time could be monitored. Three separate acquisitions were performed with in-plane resolutions of 1.875 mm (64^2 matrix), 1.25 mm (96^2 matrix), and 0.934 mm (128^2 matrix), respectively. Each dataset was then denoised with the blind fMRI estimation scheme described in [3] using a Haar wavelet and one level of decomposition. This Haar wavelet-basis can be shown to be well suited to fMRI data when small regions of activation are of interest. No other processing was performed.

Contrast detection was performed on the original (i.e., non-denoised) and denoised data using a standard t-test and a Bonferrioni-corrected threshold (p=0.05). The SNR of each acquisition was estimated from the original data as the mean of a homogeneous brain region divided by the standard deviation of a background region. The CNR was estimated for each voxel in all six datasets by dividing the deviation of the mean stimulus response from baseline by the standard deviation of the time-course during periods known to not contain a BOLD signal. The mean and standard deviation of the CNR of voxels detected as active in the visual cortex in original data were used as a measure of the CNR obtained at the different in-plane resolutions before and after denoising. Visual cortex voxels detected active only in the denoised datasets were not included in this measure.

Results

Figure 1 shows the active voxels detected at each resolution before and after denoising. The relationships between in-plane resolution, and the SNR and CNR of the data are shown in Figure 2. As resolution increases, the extent of activation in the visual cortex of the original data decreases due to the lower SNR and CNR. After denoising, more active voxels are detected at all resolutions and the extent of activation in the visual cortex of the high-resolution data is better matched to the extent of activation in low-resolution maps. The absence of contralateral activation in the denoised data demonstrates that the estimation scheme did not introduce significant false positives. As expected, as resolution increases, both the SNR and the CNR in the original data decreases. The CNR decreases at a much slower rate due to the better matching of voxel size to functional unit size at higher resolutions. Additionally, the variance of CNR decreases at increased resolution. After denoising, the average CNR of the active voxels is increased by more than one standard deviation for all resolutions, allowing for more robust detection of activation. To achieve a similar CNR improvement without denoising, the acquisition time would need to be increased by a factor of approximately two.

Conclusion

Appropriate denoising of fMRI data greatly improves the CNR of active voxels despite the loss of SNR at higher resolution. This enables robust detection of BOLD activation in sub-millimeter event-related fMRI at 3T.

References

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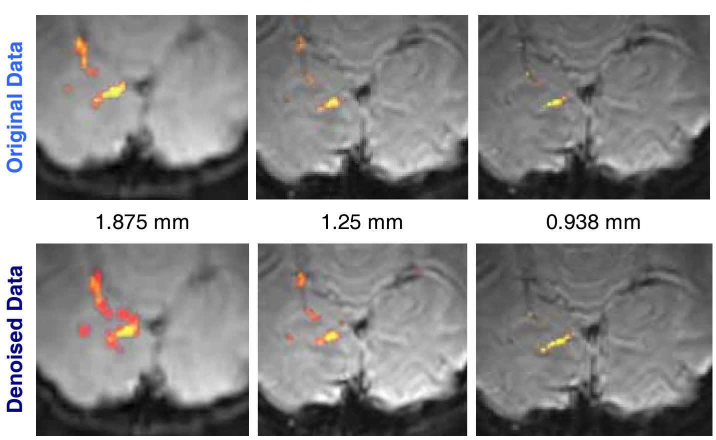

Fig. 1: Activation detected in the original and denoised data at different in-plane resolutions.

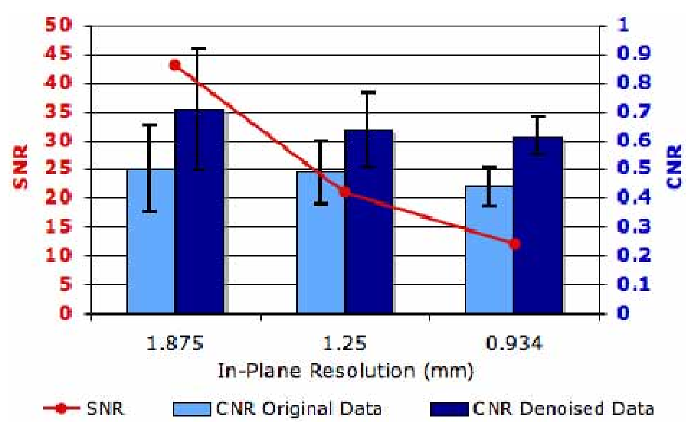

Figure 2: SNR and CNR as a function of in-plane resolution