Paying attention to somatosensory fMRI design

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Introduction: Improving the sensitivity of BOLD fMRI to small changes in MR signal intensity can potentially improve indirect detection of neural events and elucidate features of the BOLD signal in response to changes in neural activity. This requires pushing the limits of spatial and temporal resolution while maintaining high contrast-to-noise ratio (CNR). The trade-off between spatial resolution and signal intensity limits the attainable CNR; however, in the visual cortex, it has been shown that reducing voxel size increases CNR by minimizing partial volume effects[1]. To date, there has been no systematic study to optimize experimental methodology in terms of scan parameters and task design for somatosensory fMRI. We hypothesize that task design plays a more critical role than optimization of imaging parameters. Consequently, we investigate several scan protocols using different spiral acquisitions to compare CNR during active and passive task conditions.

Methods: Somatosensory fMRI was performed on six healthy right-handed adults at 3 T (Signa 3T/94 configuration, General Electric) using a 5" surface coil. **1. Scan protocols:** Voxel size and number of interleaves for spiral acquisitions (FOV = 14 cm, 6 coronal slices 4 mm thick) were varied in five separate scans using TE/θ values optimized for an effective TR of 1000 ms: i) 1-shot, 64x64 (TE/TR/θ = 30/1000/50°); ii) 1-shot, 128x128 (TE/TR/θ = 30/1000/50°); iii) 2-shot, 128x128 (TE/TR/θ = 30/500/40°); iv) 1-shot in/out (IO), 64x64 (TE/TR/θ = 30.4/1000/50°); v) 2-shot IO, 100x100 (TE/TR/θ = 30/500/40°). Isotropic in-plane resolution for low and high resolution scans was 2.2 mm and 1.1 mm, respectively. Anatomical axial images were acquired using conventional spoiled gradient echo imaging. **2. Active Task:** Variable-duration 30 Hz vibrotactile stimuli were delivered[2] to the right index finger. Each scan consisted of three 0.5 s stimuli, two 2 s stimuli, one 4 s stimulus, one 6 s stimulus, and one 20 s stimulus, presented in random order and each followed by 16-25 s of rest. Subjects were instructed to tap twice in succession (~1 Hz) with the thumb and index finger of their left hand when the shortest stimulus duration was detected. **3. Passive Task:** A subset of three subjects participated in an additional passive scan (p_1-IO64) at the end of the session in which no motor response was required. Subjects were instructed not to attend to the stimuli. **4. Analysis:** Activation maps were created in AFNI[3] using a boxcar convolved with a hemodynamic response function as the reference waveform, which excluded all motor trials, for cross-correlation. Voxels within an ROI encompassing primary somatosensory cortex (SI) were analyzed. All 1-shot IO acquisitions were also reconstructed to yield spiral-out data only (1-64IO_out).

Results

CNR for active and passive tasks is plotted in Fig 1 for all scan types. **1. Active Task:** Within-subject t-tests comparing CNR across scan types in the active tasks were nonsignificant except for 2-128 compared with 1-IO64, which had less CNR (t(5)=3.10, p=0.03). A nonsignificant trend was also observed where CNR in 1-IO64 was higher than its spiral-out counterpart (this difference becomes significant if one outlier is removed, t(4)=3.20, p =0.04). No effect of scan order in the active tasks was found. **2. Passive Task:** CNR was significantly larger in the active task (1-IO64) compared to the equivalent passive scan (p_1-IO64). Activation maps showed less activation in all three subjects during the passive task compared to the active task (t(2)=6.60, p=0.02) for the same scan type (1-IO64). Activation maps for a representative subject (N5) are shown in Fig 2 and illustrate the more robust activation obtained in the active vs. the passive task conditions at two statistical thresholds (Bonferroni-corrected and uncorrected).

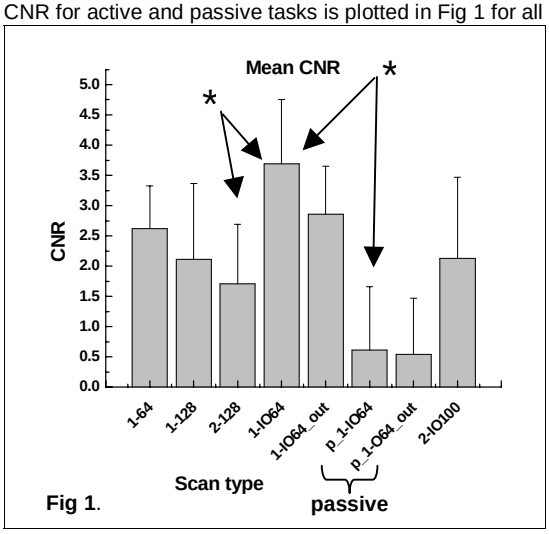

Fig 1.

Discussion

This study examined the effect of task design and scan parameters on CNR during somatosensory fMRI. Choice of scan parameters was limited by the need for enough slices to adequately cover SI while maintaining an effective TR of 1000 ms for good temporal resolution. Results show that CNR is dependent on task design (i.e. active vs. passive conditions) within the same scan type (1-IO64). One major difference between these conditions lies in the level of attention given to the stimulus. Although difficult to control and quantify, attention has been shown to affect somatosensory fMRI responses in SI[5]. Varying scan parameters, on the other hand, only produced a significant difference in one pair of scan protocols: the CNR in 2-128 was smaller than values in 1-IO64. Lack of significant difference among the remaining comparisons in the active condition suggests that 1) the choice of scan parameters is secondary compared to the design of the task paradigm; and 2) increasing isotropic spatial resolution in spiral acquisitions to 1.1 mm, a four-fold decrease in voxel volume compared to 2.2 mm spatial resolution, does not reduce BOLD contrast. The data also show that there is no apparent difference in CNR between single and double-shot spiral out sequences, consistent with reported findings in sensorimotor cortex[7]. Additionally, the difference between the CNR of 1-64IO and 1-64IO_out scans (significant when one outlier was removed) was consistent with results of experiments conducted in non-uniform brain regions[6]. This difference cannot be attributed to attention because both scan types were reconstructed from the same fMRI scan. The preliminary results presented here indicate that choosing a small voxel size with a single-shot acquisition does not compromise BOLD contrast, and will help ongoing experiments to establish an experimental protocol optimized for BOLD contrast and spatial resolution in somatosensory fMRI. In light of recent work[7], such methodological advances are necessary for detailed investigations of the underlying neurophysiology of the somatosensory cortex that can influence characteristics of the BOLD signal, such as transient and sustained responses from rapidly- and slowly-adapting neurons.

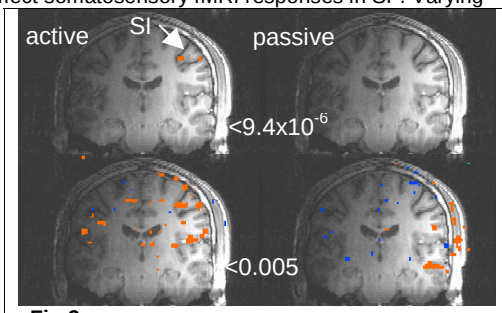

Fig 2.

References: 1.Yacoub et al MRM 49(4): 655-664 (2004); 2. Graham et al, Magn Res Med 46:436-442 (2001) 3. Cox, Comput Biomed Res 29:162-173 (1996); 4. Arthurs et al, Exp Brain Res 157: 267-274 (2004); 5.Glover and Lai, MRM 39:361-368 (1998); 6. Glover and Law, MRM 46:515-522 (2001); 7. Nangini et al, MRM (in press).