A Parallel Transmission Method for Improved BOLD fMRI

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Introduction: Signal loss due to susceptibility variations is a major limitation in BOLD fMRI (1-3). Many important brain regions such as the orbitofrontal cortex (OFC) are difficult to observe as a result. Parallel transmission z-shim techniques have been shown to be promising for reducing susceptibility artifacts (4), however, no application has been demonstrated. We present a parallel transmission method for improved BOLD fMRI, including a customized TR head array, where unique slice-select pulses are applied on each channel to reduce signal loss in the OFC. The method is demonstrated to increase OFC activation during a breath-holding task at 3T.

Theory: Susceptibility variations in axial slices above the sinus regions create predominantly through-plane (*z*-direction) gradients that lead to signal voids. It has been recently demonstrated that parallel transmitters can reduce signal loss by applying independent time-shifted pulses through each transmitter to create a simultaneous z-shim (4). Given a time-shift (or through-plane susceptibility gradient) map t_j, where j indexes M spatial locations, and coil sensitivity maps s_{ij}, where i indexes N transmitters, the small-tip solution for the each pulse on a transmitter $b_i(t)$ producing a rectangular slice is:

$$b_i(t) = \sum_{j=1}^{M} s_{ji}^{-1} \mathrm{sinc}(t - t_j)\,.$$

The matrix inverse of the coil sensitivity can be found by any standard technique. The corresponding z-gradient is the same for all pulses and is determined by the slice thickness and pulse bandwidth.

Methods: The pulses were implemented in a standard spiral sequence (TE/TR=30/2000ms, 22cm FOV, 8 slices, 5mm thickness, 60° flip angle, two interleaves, 64x64) on a Siemens 3T scanner with a custom Tecmag four-channel transmission system including a four-channel TR array and four 300W amplifiers. Figure 1 (a) shows the four-channel head array. The array uses eight coils configured such that the bottom five coils are combined into one channel to cover posterior brain regions. The three top coils covered anterior regions including the OFC. The sensitivity maps s_{ij} of the four channels are shown in Fig. 1 (b). The time shift map t_j was found by shifting the pulses on all four transmitters progressively through 17 selected shifts from -400μs to 400μs. At each step, the time shift value was assigned to locations where through-plane phases were completely cancelled out by that amount of shift. Two four-minute breath-holding (20 seconds on/off) fMRI experiments were conducted on three healthy human subjects.

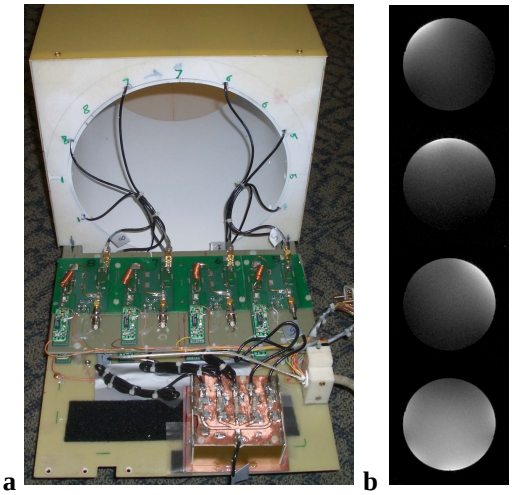

Figure 1 (a) Four-channel/eight-coil TR array optimized for imaging the OFC. The bottom five coils, combined into one channel, and the top three can independently transmit RF pulses **(b)** Sensitivity maps of the four channels.

Results: Figure 2 (a) show four axial slices, with activation overlaid, acquired above sinus from a scan without shimming (top row) and with shimming (bottom row), respectively. Signal recovery and improved activation from the breath-holding fMRI paradigm in these slices can be clearly noticed. Figure 2 (b) shows the time course of the signal within the square ROI. The blue and red lines are from the scans with shimming and without shimming, respectively. A time course following the 20-second on/off block design can be observed in the blue line.

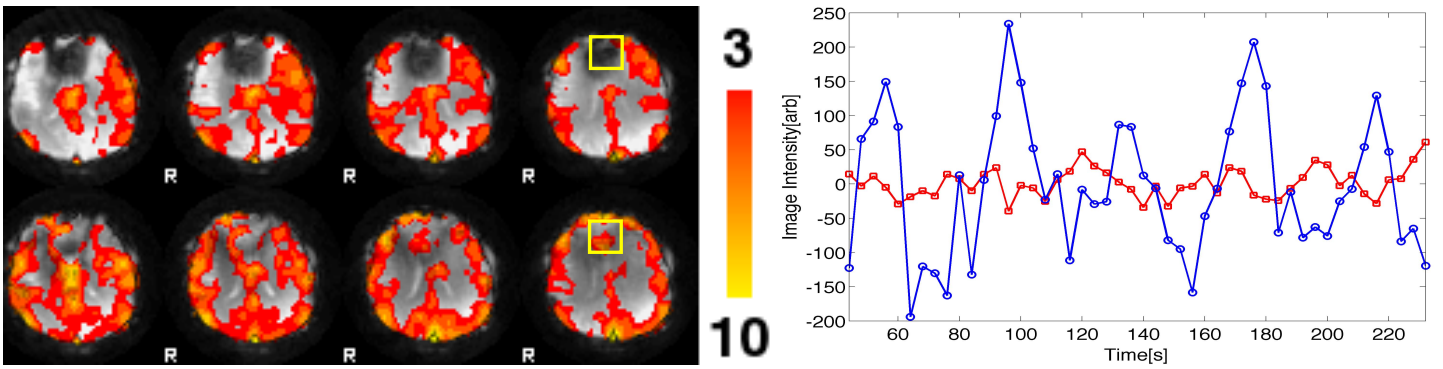

Figure 2 (a) Four axial slices acquired without shimming (top row) and with shimming (bottom row). Note the signal loss in the OFC in the top row is recovered in bottom row. Increased activation is also noticeable in the bottom row. **(b)** The time course of the fMRI signal within the marked ROI. Blue and red lines are shimmed and un-shimmed data, respectively.

Discussion and Conclusions: A parallel transmission method for improving BOLD fMRI of inferior brain regions is presented. Recovered signal and increased activation in the frontal brain is observed.

References: (1) R. T. Constable, JMRI 1995;5:746. (2) G. H. Glover, MRM 1999;42:290-299. (3) V. A. Stenger *et al.* MRM 2000;44:525. (4) W. Deng et al, Proc. ISMRM 16(2008):622.

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