A new real-time functional magnetic resonance imaging method for neurofeedback

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Objectives Recently, fMRI has been applied in "neurofeedback" (NF) experiments, enabling individuals to modulate behaviour in near real time in response to brain activity. As an alternative to commonly used fMRI methods for on-line visual feedback such as EPI or spiral imaging, an imaging technique is developed that localizes a column of tissue using *outer volume suppression* (OVS) and provides multi-echo (ME) acquisition to sample T_2^* decay in great detail. The advantages of this technique are enhanced BOLD contrast sensitivity by echo summation and reduced data processing time due to reduced data size. These advantages have been confirmed by experiment, indicating that the implementation and validation of the prototype ME acquisition technique has favorable features for performing fMRI NF experiments.

METHODS The ME pulse sequence consists of: (1) an OVS sequence using *very selective suppression* (VSS) pulses [1] to suppress signal outside the *volume of interest* (VOI); (2) a standard slice-selective 90° RF excitation to enhance spatial localization and to excite the VOI; and (3) a multi-gradient-echo readout using "flyback" gradients [2] to provide detailed sampling of the resulting T_2^*-decay and to resolve the VOI spatially into a strip of coarse voxels. Using MATLAB, data were reconstructed to provide a T_2^* decay curve for each coarse voxel (Fig. 1). Prior to echo summation, BOLD contrast was optimized by weighting each echo signal with its relative expected BOLD contrast contribution using the method of Poser et al. [3]. The temporal noise of the resulting time series was reduced by applying motion artifact correction using a subtraction method [4] and by suppressing respiratory-related artifact with a low pass filter (cut off frequency, 0.19 Hz).

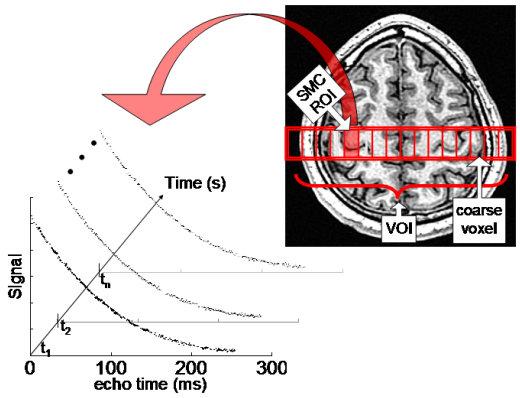

Fig. 1. Placement of the VOI (2 x 2 x 16 cm^3, large box) that is spatially resolved into 16 coarse voxels (indicated by the grid). From the SMC ROI (colored patch), T_2^* decay curves as a function of echo time were acquired during each TR (time points t_1, t_2,…t_n).

Experiment: Both ME (TR=1s, 20 mm slice, TE=5ms - 267ms with 256 evenly-spaced echos for matrix size = 1x32 and TE=5ms - 365ms with 356 echos for matrix size=1x16, 16 cm FOV) and spiral-in/out k-space imaging protocols (TE/TR/θ=40ms/1s/60°, 5 mm slice, 64 x 64, 20 cm x 20 cm FOV) were performed with a standard head coil on a GE 1.5 T MR scanner. Six right-handed participants performed finger tapping using their non-dominant hands in a block design that consisted of 20 s of task and 20 s of rest for a total of 5 min for each protocol. Using AFNI software [5], spiral data were corrected for motion, linear and quadratic trends, and spatially smoothed using a Gaussian filter (FWHM = 6 mm). The spiral imaging voxels within each corresponding coarse voxel location were delineated and their time series were averaged. The coarse voxel encompassing most of primary *sensorimotor cortex* (SMC) and consisting of the highest number of activated spiral imaging voxels was labeled as the SMC *region-of-interest* (ROI) (Fig. 1). Percent BOLD signal change was determined by the ratio of the estimated coefficients of the reference waveform to that of the constant baseline from linear regression of time series data from SMC ROI. Processing time was determined by the time for a custom "real-time" algorithm performed using MATLAB on a laptop (Intel Pentium M 725 processor and 512 MB RAM memory) to undertake steps from reading previously acquired raw ME data from disk after each TR to displaying a scrolling chart of time series data. The motion artifact correction and low pass filter were implemented using the sliding-window approach [6], in which 30 time points were processed together.

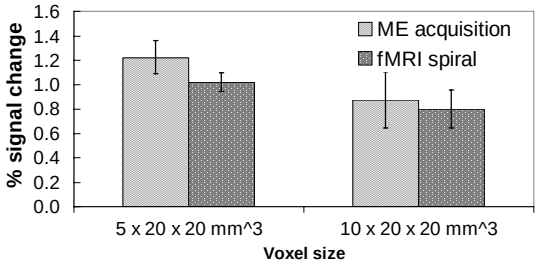

Fig. 2. The average activation-induced BOLD % signal change in SMC ROI across participants. Error bars indicate standard error of the mean.

RESULTS AND DISCUSSION Four out of six participants showed significant activations within the SMC ROI. The average activation-induced BOLD % signal changes across participants range from 0.8% - 1.2% (Fig. 2). However, there are no significant main effects of imaging protocols and voxel size on percent signal change, suggesting that the two protocols provided comparable BOLD contrast. The estimated processing times are 284 +/- 60 ms and 214 +/- 23 ms for the 1x32 and 1x16 datasets, respectively, indicating significantly reduced computational intensiveness to compute ME data. Results from this work suggest that the proposed method may be used to provide real-time feedback in fMRI NF experiments.

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