Real-time fMRI-guided MR Spectroscopy

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Introduction:

Although magnetic resonance spectroscopy (MRS) and functional magnetic resonance imaging (fMRI) are extraordinarily promising new imaging modalities that are improving our understanding of the pathophysiology of many diseases, these two tools have been essentially used exclusively and independently. Functional MRI is used to map brain networks that underlie behaviors, but specific metabolic dysfunctions underlying functional abnormalities cannot be discerned from fMRI data. In contrast, MRS measures neurochemical and metabolic parameters that might clarify the meaning of fMRI abnormalities, but MRS measurements are typically obtained from single voxels that are placed anatomically and may not correspond with areas of specific brain dysfunction. However, by placing MRS voxels based on fMRI indications of dysfunction localization it is possible to integrate the information derived from fMRI and MRS to better understand human brain function. In this work, we present a real-time fMRI-guided MRS system for obtaining metabolic information with improved tissue specificity from regions of interest identified by fMRI.

Methods:

We have implemented the real-time fMRI-guided MRS system on a Varian 4T whole-body MRI scanner and tested on one healthy right-handed volunteer with a visually-cued finger tapping protocol. The fMRI protocol is 5-minutes long consisting of alternating 30 second epochs of right- and left-handed finger tapping. The visual stimulus was synchronized with the EPI acquisition via TTL trigger. During acquisition, EPI data (inter-volume interval = 3 sec.) is stored on the scanner console computer (Sun Blade 2000). An in-house program on the scanner console monitors the output FID file and copies each EPI volume (i.e. 30 EPI slices) into a NFS-mounted directory on a second computer (Sun Blade 1500). The second computer monitors this directory and reconstructs each new EPI volume via an in-house IDL code, saving it to a second directory. A third in-house program monitors the reconstructed data in the second directory and submits data to the AFNI "real-time plugin" (1-3) for processing. The AFNI real-time plugin performs motion correction (3) and calculates correlation coefficients of the EPI data with an ideal waveform using a recursive cross-correlation formulation (2). These results are then displayed as a functional map overlaid on the subject's previously acquired T1-weighted anatomic images. In this experiment, the ideal waveform for correlation consisted of a square wave set to one during right-hand tapping and zero during left-hand tapping. The cluster of activation in the left primary motor strip was identified in AFNI and the coordinates of the cluster center of mass and the cluster dimensions were transferred automatically to the scanner for spectroscopy voxel prescription by in-house code.

Results:

During EPI data acquisition, the fMRI activation map was continually processed and updated. The fMRI overlay was thresholded at a voxel level threshold of $P > 10^{-7}$ and cluster volume greater than 320cc. Figure 1 illustrates the thresholded real-time fMRI activation map at 1, 3, and 5 minutes of acquisition from left to right, respectively. Red and yellow colored regions represent the right hand finger activation map, while the blue colored regions represent left hand activation. Activation volumes for right-handed finger tapping in the left primary motor strip were observed to increase and reach a plateau (data not shown). After the fMRI map was obtained at the end of scan, the region of interest (shown in Figure 2) for MRS voxel prescription was determined and the location and voxel dimensions were automatically transferred to the scanner console for MRS acquisition. The time differential between EPI volume acquisition and fMRI activation map update was approximately 4 seconds.

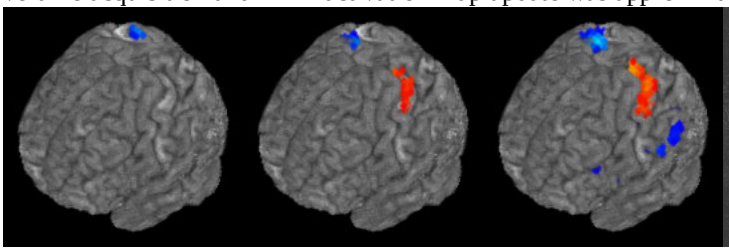

Figure 1. Volume rendered subject brain and superimposed real-time FMRI statistical parametric map at 1, 3 and 5 minutes (left to right).

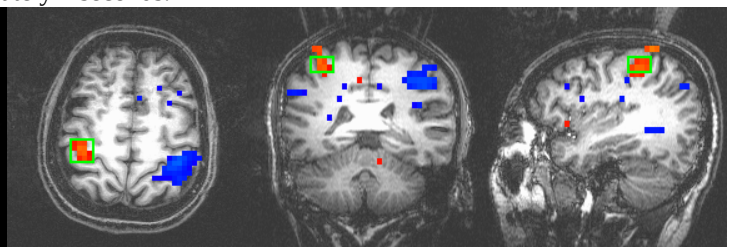

Figure 2. Spectroscopy voxel (green) prescribed to contain the region of left primary motor strip identified after 5 minutes of FMRI acquisition.

Discussion:

We have successfully demonstrated that real-time fMRI can be conducted during EPI data acquisition and that regions of activation identified by fMRI can be used on-line to prescribe MRS. With a few modifications, we believe the 4 minute lag in the production of fMRI results can be reduced. In the current implementation, real-time fMRI analysis is constrained to protocols that have a predetermined ideal activation waveform for correlation analysis. Because activation volume depends on both voxel level and cluster volume thresholds, methods for a priori determination of cluster volume and probability thresholds are needed. The reproducibility and specificity of the technique needs to be evaluated.

References:

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