Automated Real-time Tracing of Functional MRI Signals from Multiple Cortical Areas

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Introduction: EEG provides fast detection and relay of the electrical activity detected from the brain surface. However, because signals are only recorded at the scalp, accurate localization of regionally specific brain activities depends on solving inverse problems that are inherently ill-posed [1]. With the advancement in data communication hardware as well as in image processing speed, real-time characterization of the fMRI data is now possible. It has been applied for adaptive multi-resolution data acquisition schemes [2], neurofeedback applications [3,4], and brain-computer-interfaces (BCI) [5]. In spite of these advancements, many of the current methods of detecting dynamic BOLD signal associated with the cortical activity has been subjected to either a non real-time domain or tracking of a limited number of pre-defined regions-of-interest (ROIs). Combined with real-time image reconstruction and processing, we present a method to measure functional MRI signals from multiple cortical areas simultaneously in real-time. Unlike EEG-like signal measurement from a multiple surface electrode montage, dynamic and real-time recordings of BOLD signal from the parcellated brain areas reflects the underlying cortical activities directly rising from the various locations of the brain.

Method: The study was approved by the local Institutional Review Board. Three male (aged of 20 to 35 year old), right-handed healthy volunteers participated. The study was conducted in a 3 Tesla clinical scanner (Signa VH, GE) using standard birdcage head coil for RF transmission and detection. The image data, saved as raw data file (without reconstruction), was transmitted to the computational platform (notebook PC, operating at Intel 2 GHz CPU) via Ethernet connection (2Giga bit/second bandwidth) using FTP (file transfer protocol) script (RoboFTP, Serengeti Inc). Matlab (Mathworks, MA) computation environment was used for the data reconstruction and processing. In order to enable the tracking of the BOLD signal activities from the desired ROI, an automated segmentation of the anatomical images were needed whereby the schematic of the registration procedure is shown in Fig. 1. Two pre-segmented anatomical templates, *i.e.*, the Brodmann's area (BA) image and the Automated Anatomical Labeling (AAL) image, were downloaded from MRIcro (www.mricro.com version 1.39). These template images (X:Y:Z=181:217:181, 1mm^3 isotropic voxel) were labeled with different numerical indices. In order to segment and label the EPI data for later user-interaction, template segmentation maps were first registered to the normalized EPI image, and used as a reference space (ICBM$_{152}$ Space: International Consortium for Brain Mapping; X:Y:Z=91:109:91, 2mm^3 isotropic voxel, SPM2). Before the initiation of the functional scanning, an individual's EPI anatomy (X:Y:Z=64:64:13, 3.75x3.75x 5.5 mm^3 voxel size) was registered/normalized to this reference EPI image. During this process, the chosen EPI images were heavily T2-weighted for a better tissue contrast. Real-time EPI then proceeded while subjects were performing hand motor tasks (clenching of right or left hand). All the proceeding EPI data volume was realigned to the first image volume set using affine transformation and updated before the end of the next image volume (less than 1 second per volume is needed). Users can select multiple brain locations based on the list provided by the AAL or BA map, and averaged BOLD signal from the regions are displayed (in term of % signal change from the baseline level). Optionally, spatial operations, such as adjunction, union, exclusion operators, can be applied to further modify the spatial areas to be selected.

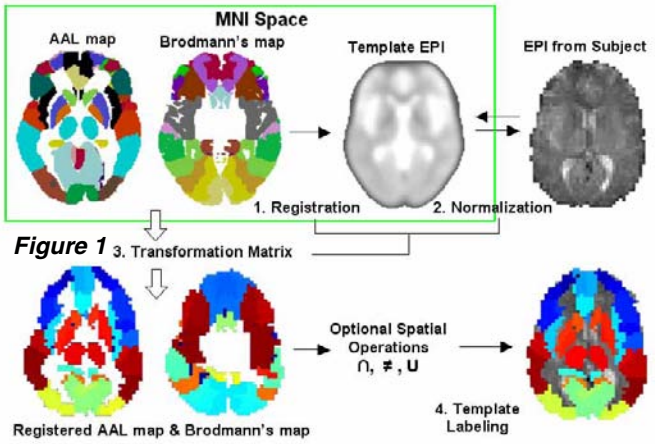

Figure 1

Results: The proposed method of automated real-time processing and display of cortical activities was successfully implemented across all subjects. The average time delay from the actual data acquisition to file transfer and data display was approximately 2s for the given hardware platform. Since there were more than 70 anatomical areas and more than 30 Brodmann's areas whereby the BOLD signals are potentially extracted from (considered as 'display channel'), the operator viewed the BOLD activities measured from all available regions, and selected only these regions showing task-related activity. An example of measurement from some of representative regions with significant activities from one subject is shown in Figure 2 (left hand: blue line; right hand: red line; y-axis: % signal increase; x-axis: seconds; thick-bar indicate the timing of task) whereby the task-related signal modulation is evident. Left superior medial frontal gyrus (#8 in Fig.2) is shown as an example of quiescent areas without the evidence of task-related activity.

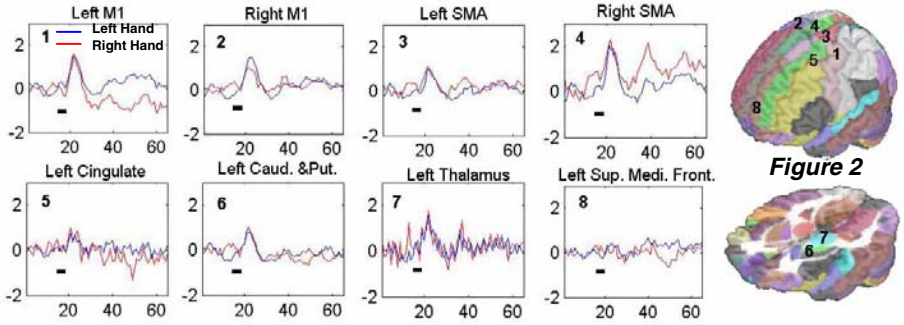

Figure 2

Discussion: The format of the data display and output shares many features with those of EEG recordings. In addition, similar to the evoked potential measurement, the method can detect event-related fMRI signal changes. Although the temporal resolution of fMRI is much slower than that of the conventional EEG recordings due to slowed hemodynamic nature of the BOLD signal, the high-spatial resolution and automated anatomical segmentation/labeling can be used for following unique clinical applications: (1) Neurofeedback-enabled fMRI; (2) Brain-computer-interface (BCI) to associate cortical activity with computer commands; (3) epileptic seizure detection; and (4) subject-driven task performance for presurgical cortical mapping to emulate awake intra-operative electrocortical stimulation.

Reference: [1] Chauveau et al. Hum Brain Map. (2004) 21(2):86-97, [2] Yoo et al. Neuroreport. (2004) 15(10):1591-5. [3]deCharms et al. Neuroimage (2004) 21(1):436-43. [4] Posse et al. Neuroimage (2003)18(3):760-8. [5] Weiskopf et al. IEEE Trans Biomed Eng. (2004)51(6):966-70.