Brain-Computer-Interface using fMRI: Spatial Navigation by Thoughts

S-S. Yoo[1,2], T. Fairneny[3], N-K. Chen[1], L. P. Panych[1], H-W. Park[4], S-Y. Lee[2], F. A. Jolesz[1]

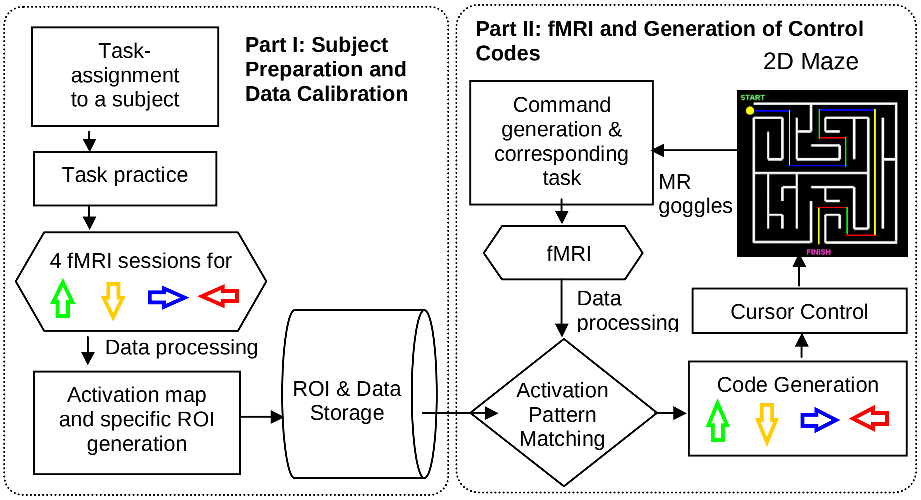
[1]Radiology, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, United States, [2]BioSystems, KAIST, Daejeon, Korea, Republic of, [3]Biomedical Engineering, Boston University, Boston, MA, United States, [4]fMRI Laboratory, KAIST, Daejeon, Korea, Republic of

Introduction: A brain-computer interface (BCI) is a way of conveying individual's thoughts to control computer or electro-mechanical hardware without any overt muscle activities [1]. Potential utility of BCI is currently being evaluated in the field of rehabilitation and robotics. Since BCI detects signals generated from responsive or intentional brain activity, to date, most BCI systems use electroencephalography (EEG) recordings as the connection between the brain and the computer, whereby the amplitude or temporal pattern of the brain activity associated with task are interpreted as analogue control signal [1]. Capitalizing on the ability to characterize the spatial pattern of brain activity in a reproducible manner [2], we were motivated to explore the possibility of using fMRI to interpret the spatial distribution of brain function as the BCI commands. With a spatial resolution in the millimeter range, the analysis of fMRI data can now be done in real-time. The proposed fMRI-BCI method takes advantages of these new advancements to analyze the brain activities and determines the corresponding computer commands for the spatial navigation through a 2D-maze.

Method: BCI fMRI experiment was conducted using EPI sequence (TR/TE=3000/40 msec, 20 axial slices, 3.75 x 3.75 x 5 mm voxel dimension) with a 3-Tesla MR system (GE Medical Systems). Data analysis and image reconstruction were performed using in-house fMRI processing software written in MATLAB codes (Mathworks, MA) [3]. The raw fMRI data was temporarily stored in the MR control station, where it was then transferred to a computational workstation for data processing and image reconstruction via Ethernet connection (~100 mega bps speed). Interpreted fMRI data was finally relayed to a notebook computer that contained the maze problem.

Exemplary data was acquired from 2 healthy male subjects, aged 25 and 26. The study was approved by the local IRB. As illustrated in the Figure, the BCI procedure was divided into two stages. In the first part, the subject was given four distinct mental tasks to perform and practiced them before the actual fMRI sessions. These tasks were (1) simple mental calculation (sequential number subtraction), (2) covert speech generation, (3) motor imagery of the clenching of the right hand, and (4) motor imagery of clenching of the left hand. These tasks were later translated to the computer cursors - (1) up, (2) down, (3) right, and (4) left respectively. Each fMRI session, based on the block-based design, consisted of three 15-second blocks of mental task interleaved by four blocks of 15-second rest periods (passively listening to a computer-generated 900 Hz monotone presented at 2 Hz rate). Each of the four tasks performed activated specific areas in the brain, which were used as the template fMRI maps. Four distinct region-of-interests (ROIs) were manually delineated to represent four simple computer commands (up, down, left, and right), and stored to provide reference data for the subsequent BCI fMRI sessions.

After completion of the first stage, the subject was then introduced to a simple 2D-maze via MR-compatible goggles. The maze required a minimum of 12 steps to complete. An automatic stop function was added at each decision-making point. After planning the best path for getting through the maze, the subject determined the direction and performed the corresponding imagery task for that movement. fMRI sessions using identical scan parameters as the calibration session were conducted while the subject performed each task. Near real-time data processing was used at the end of each scan to analyze the raw data and match it to one of the four templates previously stored from the first stage. Dice Similarity Coefficient (DSC) between template activation maps was calculated to determine the best spatial-match out of the four functional templates in ROIs. The cursor in the maze then moved in the direction correlated with the task. In order to evaluate the accuracy of the BCI method, the subject was asked about whether his intention coincided with the results of fMRI BCI at the end of each scan session.



Results: The processing time for each fMRI session (the scan time was 1 min 51 seconds including 5 dummy scans) was typically less than 15 seconds, providing near real-time processing capability. Four distinct patterns of global activation were found from each task. Among them, (1) bilateral activation in the dorsolateral prefrontal cortices were representative of mental calculation, (2) left Broca's area (inferior frontal gyrus) and auditory association areas for covert speech task, (3) left somatomotor areas for right hand imagery, and (4) right somatomotor areas for the left hand imagery, were identified as task-specific ROIs. Using the proposed fMRI BCI method, a 25-year old subject successfully reached the end of the maze within 13 steps (one misidentified for the 'move to right' instead of 'move to left'), resulting in an accuracy of 92.3%. The other subject completed the task without any error in 12 required steps.

Discussion: The method, implemented in a high-field MR system, was designed to detect the different spatial patterns of brain activities generated from four different covert functional tasks performed by the subjects. Each task was then interpreted as predetermined computer commands to move the cursor for the spatial navigation. Based on our preliminary data, we concluded that fMRI could indeed be used as a working BCI prototype. Although the current method suffers greatly from the marginal temporal resolution (typically 2 minutes for the command generation), we have shown that spatial distribution of activation characterized by real-time fMRI can be used as the source signal for BCI. Further investigation is directed toward increasing the degrees of freedom to the BCI commands (to the degree of spelling alphabets) and increasing the temporal resolution using the event-related fMRI design.

References: [1] Wolpaw et al. IEEE Tans Neural Syst Rehabil Eng. 11:204-207(2003); [2] Machielsen et al. Hum Brain Mapp. 9:156-164 (2000); [3] Yoo and Jolesz, NeuroReport, 13:1377-1381 (2002)