Brain-Computer-Interface using real-time fMRI: Thought-controlled robot arm

J-H. Lee[1], J. Ryu[2], F. A. Jolesz[1], Z-H. Cho[2], and S-S. Yoo[1]

[1]Radiology, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, United States, [2]Gachon Medical School, Incheon, Korea, Republic of

Introduction: The utility of functional MRI (fMRI) is rapidly increasing for both clinical and research purposes. Based on the ability to reveal neuronal activation with both superior spatial localization and fair temporal resolution in a non-invasive way, a real-time approach to fMRI (rtfMRI) has shown efficacy in several potential applications such as brain-computer-interface (BCI) [1] or neurofeedback [2,3]. In this context, we tested the feasibility of using rtfMRI to translate the activity from the primary motor cortex during a thought process (imagery without the involvement of peripheral muscles) into movement of a robotic arm. This movement of the robotic arm was visually fed back to the subject, thus allowing the subject to control cortical activation in order to achieve a pre-defined course of the robotic arm movement.

Method: Healthy right handed volunteers were recruited according to ethical guidelines. A 3-Tesla clinical scanner (Signa, GE) was used to detect blood oxygenation level dependent (BOLD) contrast based on a gradient EPI sequence (TR/TE=1000/35ms; FA=80°; FOV=24×24cm^2; 64×64; 3.75×3.75mm^2 in-plane resolution; 5mm slice; 1mm gap; 13 axial slices). Fig. 1 shows a schematic diagram of an overall data processing scheme. Two hand motor imagery tasks (right-hand: 'RH'; left-hand: 'LH') were employed. The subject performed each task separately using a block design (150s; three 20s task periods interleaved by four 20s rest periods). The obtained EPI data were immediately transferred to a laptop via file transfer protocol (FTP) with movement correction. The realigned EPI volumes were then analyzed using a cross-correlation method whereby the voxel-wise correlation coefficients (CC) between the BOLD time series and the canonical HRF in SPM2 were obtained. After thresholding the CC maps to visualize the activation, a single voxel was manually selected to exclusively represent the left primary motor area (M1) for the RH task and the right M1 for the LH task. A region-of-interest (ROI) was then defined for each task using the selected voxel and four adjacent voxels (anterior/posterior/left/right) in the same plane.

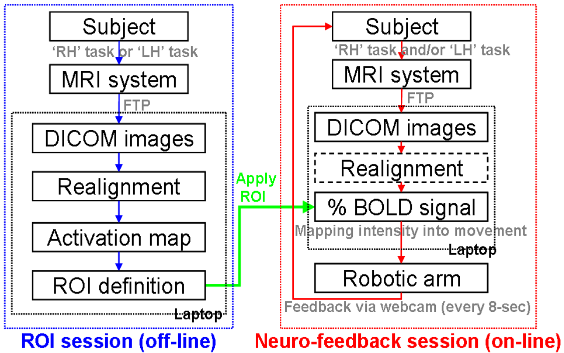


Fig. 1. A diagram of real-time fMRI for control of robotic arm

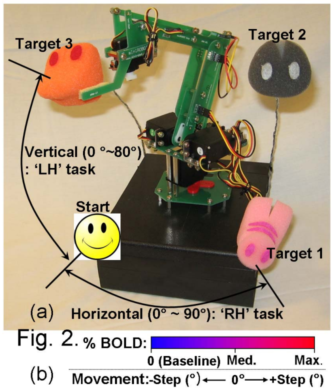
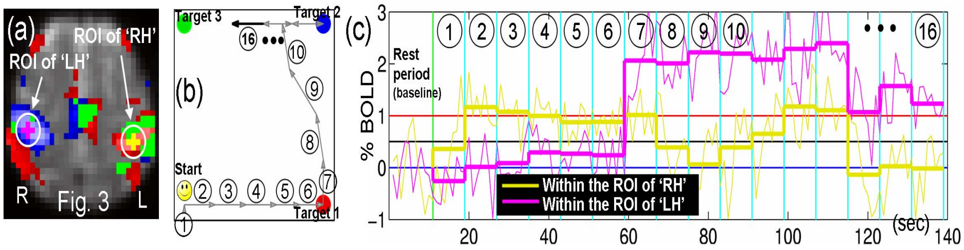


Fig. 2.

During the subsequent real-time session, represented by Fig.1 (using the same imaging parameters as in the ROI session; 150s), the averaged percent BOLD intensities within two ROIs were calculated and mapped into movement of a toy robotic arm (Fig. 2). For the real-time session, the subject was instructed to freely engage the two employed tasks in order to achieve the goal of hitting three pre-defined targets through movement of the robotic arm (Fig.2a; example of hitting Target 3). The degree of engagement of the RH and LH tasks by the subject (in terms of averaged percent BOLD intensities within the ROIs) was translated into horizontal and vertical movements of the robotic arm, respectively (Fig.2b). The mapping parameters ('Med' & 'Max' percent BOLD intensities and 'Step' degree of movement) were adjustable depending on the subject's level of BOLD contrast (e.g. for this subject: Med=0.5%, Max=1.0%, & Step=20° for both tasks). Additionally, a real-time video feed of the moving robotic arm was shown to the subject via a webcam. The MATLAB (Mathworks, MA) computational environment was used for all data processing, including FTP, on a PC (Intel 2.13GHz; 2GB RAM).

Results: Figure 3a shows the analyzed activation patterns (CC maps; $p<10^{-3}$) and defined ROIs for both tasks. Red and blue regions show the activated areas corresponding to the RH and LH tasks, respectively. The green region shows the area that is activated by both tasks. An example of the results obtained from the real-time session, illustrated by a 2-D arrow plot of movement of the robotic arm, is shown in Fig. 3b. A retrospective analysis of the percent BOLD signals within the ROIs is also shown as a time plot in Fig. 3c. Each progressive movement of the robotic arm is denoted by a number inside a circle. Based on the temporal plots of percent BOLD signals, the mean percent BOLD intensity during each 8s time frame (thick pink and yellow lines) reliably represented the subject's intention to move the arm to Target 2 after passing Target 1. These movements were confirmed to match the subject's intention via a post-scan interview.



Discussion: In this study, we presented the feasibility of achieving voluntary control of a robotic arm using the thought process that occurred during the regulation of somatomotor activation via motor imagery, as mediated by rtfMRI. Although the robotic arm was used as a means to link the thought process to explicit tangible motion, translation of these thoughts into computer control commands, such as continuous cursor movement of a computer mouse, is possible. Future applications may include (1) neurofeedback fMRI for rehabilitation and (2) an adjunctive method for EEG-based BCI. ***Reference:*** [1] Weiskopf, IEEE Trans Biomed Eng (2004) 51:966-70. [2] Yoo, Neuroreport (2002) 13:1377-81. [3] DeCharms, PNAS (2005) 102:18626-631. The work was partly supported by the grant from NIH U41 RR019703 (to Jolesz) and 5R01NS048242-03 (to Yoo)