Attentional Modulation using fMRI Neurofeedback: Preliminary Experience

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Introduction: The notion of biofeedback, a technique to allow monitoring of one's own biological indicators and signals in an attempt to gain a level of voluntary control, has been sought after to enhance/modulate physiological function. In several EEG studies with biofeedback features, the modulation of EEG frequency components was learned to alleviate symptoms associated with attentional disorders, as well as seizure-related disorders. With the advancement in fMRI data processing schemes and computational capability, the real-time/near real-time analysis of fMRI data is possible. By capitalizing on these advancements, several studies have explored the utility of fMRI for the application in neurofeedback, *i.e.*, biofeedback of one's own brain function [1-3]. Based on the experience built upon the modulation of the cortical functions in somatosensory areas using fMRI neurofeedback [1], we were motivated to modulate the cortical activation in the primary and secondary auditory areas (bilateral transverse temporal gyri and planum temporale) using selective attention to passive auditory stimulation. Selective attention, a process where the perception of certain stimuli in the environment is enhanced relative to other concurrent stimulation, is known to modulate the functions in relevant sensory areas [4]. We postulated that fMRI neurofeedback would assist subjects in achieving a significant degree of modulation in the primary and secondary auditory areas by adjusting the level of attention to external auditory stimuli.

Method: The technical focus of this study was to implement an fMRI methodology capable of acquiring, processing, and analyzing brain activation in near real-time (within few seconds after the data acquisition) using a high-field MRI system. A user-interface was constructed to enable automatic/on-site characterization and presentation of brain activity. The experiment was conducted using a high-field (3 Tesla) MR system (GE Medical), employing a near real-time fMRI data processing scheme (completed within 15 seconds at the end of each scan session) and real-time anatomical segmentation capability (Data flow shown in Fig.1).

Fig. 1 Schematics of data flow and implementation of neurofeedback fMRI

Six healthy volunteers (two females; aged 21-29 years-old) participated in the study according to the ethical standards set forth by the local IRB. The subjects were divided into two groups - one with, and the other without neurofeedback. Subject's demographic features were matched in terms of gender, age, education, handedness, and IQ. The neurofeedback fMRI protocol consisted of six baseline sessions (three pre- and three post-neurofeedback trials) and five neurofeedback trial sessions (sample shown in Fig.2). A reference scan session was conducted prior to the first baseline session to segment the target modulatory areas in the superior transverse temporal gyrus. In each fMRI session, auditory stimuli (computer generated 900 Hz tone with +/- 12% bandwidth frequency modulation at 6 Hz oscillation) was given three times interleaved by four rest conditions (15 second each) using a presentation computer (a notebook computer). The subjects were asked to change the level of attention/distraction to modulate the size of activation in the desired auditory areas. At the end of each session, *t*-test was applied to the temporal data sets across the whole image volume, and the significance in level of activation was determined at $p < 10^{-3}$. The size of activation from the segmented auditory areas was automatically measured and fed back to the subject via graphical interface (similar to the Fig.2 plot) using MR-compatible goggles. This allowed the subjects to evaluate the effectiveness of their cognitive efforts at the completion of each trial session. For the comparison group without the neurofeedback, exactly same scan protocols were administered except that the visual graph did not contain any feedback information.

Fig. 2. Example of visual feedback information, illustrating the case of positive modulation of cortical activity, measured by the area of cortical activation (solid square). Circles indicate the activity from a comparison subject without neurofeedback.

Results: An example of the results from the neurofeedback sessions (from two 22-year old, demographically-matched male subjects) is shown in Fig. 2. The subject with neurofeedback was able to achieve a significant increase in the size of activation compared to the baseline cortical activities (ranging from 32 to 56%). However, the comparison subject, without the guidance of neurofeedback, performed inferiorly (ranging from -8 to 18 %). Although preliminary, two main features were observed from our study; (1) the subjects under neurofeedback performed superiorly in modulating the size of activation than the comparison group (the maximum % increase with respect to the baseline: 45% vs. 64%), and (2) the neurofeedback group was able to maintain the enhanced level of activation better than the comparison group (two subjects in the comparison group managed to enhance the activation, but failed to maintain the consistent level of enhancement throughout the modulation trials).

Conclusion: We developed and implemented an fMRI method to deliver high-resolution definition of task-specific brain activities as real-time biofeedback signals, enabling neurofeedback. Our data indicated that neurofeedback of cortical activities in the primary and secondary auditory areas effectively assisted individuals in adjusting their level of attention to the external auditory stimulation. Our results suggest that neurofeedback using near real-time fMRI has the potential in helping individuals to voluntarily modulate anatomically-specific cortical activities. The presented method, by exploring novel task paradigm and feedback control, can be gainfully applied to study various aspects of human cognition, emotion, and behavior.

Reference:
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