Desynchronization of the mu oscillatory activity during motor imagery: A preliminary EEG-fMRI study

Hyun-Chul Kim, Jong-Hwan Lee*
Department of Brain and Cognitive Engineering
Korea University
Seoul, Republic of Korea
{hyunchul_kim, jonghwan_lee}@korea.ac.kr

***Abstract*—The purpose of this study is to identify the correspondence between distinct brain oscillatory activity acquired from electroencephalography (EEG) and blood oxygenation level dependent signals obtained from functional magnetic resonance imaging (fMRI). In this preliminary study, the changes in the mu rhythmic power (8-13Hz) during motor imagery tasks in the EEG data simultaneously acquired with fMRI data were examined. The average mu powers during the left-hand (LH)/right-hand (RH) motor imagery tasks were separately estimated after removing dominant artifacts, such as gradient artifact, ballistocardiogram artifact, and helium-pump artifact. As a result, the relatively lower mu power of the contralateral motor area during LH/RH motor imagery tasks was observed compared to ipsilateral side. This observation indicates a functional signature for motor imagery tasks.**

Keywords: Electroencephalography (EEG); functional magnetic resonance imaging (fMRI); mu rhythmic power; motor imagery; simultaneous EEG-fMRI

I. INTRODUCTION

Previous electroencephalography (EEG) studies have demonstrated that certain events can block or desynchronize the ongoing alpha rhythmic activity (*i.e.,* mu rhythmic activity) [1]. For example, event-related desynchronization (ERD) patterns in the mu rhythms (8-13 Hz) which reflects preparation and execution of hand movement is observed during motor imagery task [[2], [3]]. To prove the most distinguishable ERD patterns in the EEG simultaneously acquired with functional magnetic resonance imaging (fMRI), we examined the changes in the mu rhythmic activity during the motor imagery task.

II. METHODS AND MATERIALS

A. Participants and Experiment Design

Eight right-handed male subjects (age = 24.63 ± 4.75; handedness score = 88.82 ± 9.75 from the Edinburgh Handedness Inventory) performed left-hand (LH) and right-hand (RH) motor imagery tasks in two counterbalanced runs based on an event-related design. Each run lasted 330 s (including a 10 s dummy period at the beginning for T1-equilibration). Followed by an initial rest period (20 s), ten trials (2.5 s per trial) for LH/RH motor imagery tasks were carried out with a jittered rest period between each trial (30 ± 3 s). The subjects were instructed to close their eyes during the run and to perform each LH/RH motor imagery trial with an auditory cue (*i.e.,* a beeping sound) at the start and end of the trial via a MR-compatible auditory headset built into the MRI scanner.

B. Simultaneous EEG-fMRI Data Acquisition

EEG data were recorded with a 32-channel BrainAmp MR-compatible system (Brain Products GmbH, Munich, Germany) and BrainCap MR consisting of 32 electrodes including an electrocardiogram (ECG) electrode. All Ag/AgCl electrodes were placed according to the international 10-20 system against FCz as a reference electrode. The ECG electrode was placed onto each subject's back. The EEG signals were sampled at 5 kHz and the EEG recording was synchronized with the hardware clock for the MRI scanner (sampling rating of 10 MHz) using the SyncBox device (Brain Products GmbH, Munich, Germany). In addition, a 5 V transistor-transistor logic pulse based on echo-planar imaging (EPI) volume acquisition timing (*i.e.,* repetition time (TR) trigger) was continuously sent from the MRI scanner to the EEG recording system. The fMRI data using gradient-echo EPI sequence were simultaneously acquired (TR = 1000 ms, echo time = 28 ms, field of view = 24 × 24 cm^2, matrix size = 64 × 64, 20 interleaved slices with no gap, thickness = 7 mm) using a 12-channel head coil in a 3-T MRI scanner (Tim Trio, Siemens, Erlangen, Germany). The helium-pump in the MRI scanner was normally operated while the ventilation fan was turned off. In order to minimize the MRI scanner vibration effect in the EEG data, here, we used a cantilevered beam on which soft-sponges were immobilized to isolate the EEG cables from the MRI scanner. The amplifier was put on the cantilevered beam located outside the bore, behind the scanner.

C. Preprocessing of EEG Data

The recorded raw EEG data were preprocessed to remove dominant gradient artifact (GA) and ballistocardiogram artifact (BCA). GAs were removed using the moving average artifact subtraction [4] with the 8-volume average template through the Bergen toolbox (fmri.uib.no) provided by EEGLAB software [5]. After GA correction, the EEG data were down-sampled from 5 kHz to 250 Hz and BCA were removed using the optimal basis set [6] with the three largest principal components through the EEGLAB plug-in FMRIB (fsl.fmrib.ox.ac.uk/eeglab/fmribplugin). Lastly, a recursive

This work was supported by the Global Research Network (GRN) program funded by the National Research Foundation (NRF) of Korea (NRF-2013S1A2A2035364), in part by a grant of the Korean Health Technology R&D Project, Ministry of Health & Welfare, Korea (HI12C1847), and also in part by BK21 Plus program funded by NRF of Korea.

approach of EEG-segment based principal component analysis (rsPCA) [7] was performed to remove helium-pump artifacts through the rsPCA toolbox (bspl.korea.ac.kr/rspca.zip) implemented in MATLAB. The dummy period (for 10 s at the beginning of the scan) was then rejected in the EEG data.

D. Mu Rhythmic Power Extraction from the EEG Data

The preprocessed EEG signals across the 31 electrodes (excluding the ECG electrode) were converted into the frequency domain using short-time Fourier transformation with the 250 EEG samples (*i.e.,* 1 s) for a short-time window and no overlap between consecutive EEG segments. The maximum power within the 8-13 Hz for each electrode was used to determine individual specific mu powers. The mu power time courses within the range of the individual specific mu power ± 1 Hz were then extracted across 31 electrodes. Subsequently, the time-point rejection was performed. For example, if time points of the mu power time course within the task periods showed three times greater than standard deviation across task periods, the corresponding time points were excluded for further analysis. The sum of the power time course in the mu rhythm was then normalized to 1 and the normalized mu power levels were averaged for the LH/RH task periods, respectively. These normalized mu power levels were caluculated across 31 electodes and were averaged across all subjects. The resulting average mu power levels were used to represent topographic EEG maps.

III. Results

The topographic EEG maps during task periods represent relatively lower mu power within the contralateral motor area compared to ipsilateral side during the motor imagery task. In detail, the normalized mu power in the C4 (the right-side) electrode (mean ± standard deviation = $5.42 \times 10^{-3} \pm 8.19 \times 10^{-5}$) showed relatively lower power in the C3 (the left-side) electrode ($6.14 \times 10^{-4} \pm 2.14 \times 10^{-4}$) during the LH motor imagery task. On the other hand, the mu power in the C4 electrode ($6.24 \times 10^{-4} \pm 1.01 \times 10^{-4}$) showed relatively greater power compared to the C3 electrode ($5.86 \times 10^{-4} \pm 1.24 \times 10^{-4}$) during the RH motor imagery task.

IV. Discussion

We found relatively lower mu power in the contralateral motor area to the motor imagery task compared to the ipsilateral side. For instance, mu power in the C4 electrode showed greater power compared to C3 electrode during the LH motor imagery task and vice versa. The observation indicates that mu ERD occurs during the motor imagery tasks and is in line with previous literatures [[2], [3]]. In future studies, different frequency-band activity (*i.e.,* delta, theta, beta and gamma) should be investigated to identify functional signatures for motor imagery. Also, the correspondence between the frequency-band activity and BOLD signals should be analyzed. In addition, spectral independent component analysis [8][8] of EEG has shown a promising approach to decompose spectral EEG sources. This approach might have a possibility to investigate frequency band-specific features in the EEG data concurrently acquired with fMRI data.

V. Conclusion

In summary, the mu desynchronization in the contralateral motor areas compared to the ipsilateral sides indicates a functional signature of the mu oscillatory activity for the motor imagery.

References

[1] H. Berger, "Über das Elektrenkephalogramm des Menschen II," J. Psychol. Neurol., vol. 40, pp. 160–179, 1930.

[2] G. Pfurscheller, C. Brunner, A. Schlögl, and F.H. Lopes da Silva, "Mu rhythm (de)synchronization and EEG single-trial classification of different motor imagery tasks," Neuroimage, vol. 31, pp. 153-159, May 2006.

[3] G. Pfurtscheller and F.H. Lopes da Silva, "Event-related EEG/MEG synchronization and desynchronization: basic principles," Clin. Neurophysiol, vol. 110, pp. 1842-1857, November 1999.

[4] P. J. Allen, O. Josephs, and R. Turner, "A method for removing imaging artifact from continuous EEG recorded during functional MRI," Neuroimage, vol. 12, pp. 230-239, August 2000.

[5] A. Delorme and S. Makeig, "EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis," J. Neurosci. Methods, vol. 134, pp. 9-21, May 2004.

[6] R. K. Niazy, C. F. Beckmann, G. D. Iannetti, J. M. Brady, and S. M. Smith, "Removal of fMRI environment artifacts from EEG data using optimal basis sets," Neuroimage, vol. 28, pp. 720-737, November 2005.

[7] H. C. Kim, S. S. Yoo, and J. H. Lee, "Recursive approach of EEG-segment-based principal component analysis substantially reduces cryogenic pump artifacts in simultaneous EEG-fMRI data," Neuroimage, vol. 104, pp. 437-451, January 2015.

[8] D. A. Bridwell, L. Wu, T. Eichele, and V. D. Calhoun, "The spatiospectral characterization of brain networks: fusing concurrent EEG spectra and fMRI maps," Neuroimage, vol. 69, pp. 101-111, April 2013.