**Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006**

ThBP8.2

Estimation of Optimal Location of EEG Reference Electrode for Motor Imagery Based BCI Using fMRI

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Abstract— **Brain computer interface (BCI) is based on brain activity from voluntary will, and controls a computer system through only the imagination or other mental activity. In order to improve the performance of the BCI system based on the scalp EEG, it is important to determine suitable locations for the EEG electrodes according to brain activity as well as the location of reference electrode of the EEG, while most of conventional studies do not much consider about the location of the reference electrode. In this paper, we estimate the proper reference electrode location of the BCI system whose mental tasks are left and right finger movement imagination. The suggested location of the reference electrode is obtained by analyzing the fMRI imaging results. Further online EEG experiment confirmed that choosing supplementary motor area (SMA) as the reference is effective in enhancing the performance of the BCI system.**

I. Introduction

THE brain computer interface (BCI) is a computer interface system which is based on brain activity from voluntary will. Besides the brain machine interface based on neuronal activities, most of the BCI systems are implemented based on scalp EEG signals [1]. In order to build such a BCI system with a higher level of performance, it is essential to get reliable EEG signals. There are so many aspects to be considered when constructing BCI systems such as the appropriate mental tasks and effective signal processing and pattern classification techniques [1]. The location of the EEG electrodes is also very important, because brain activity corresponding to specific mental tasks is considerably localized. In the conventional BCI systems, the location of the EEG sensor is usually based upon the 10-20 system or other standard EEG electrode placements [1]. This approach, however, doesn't seem to be efficient and convenient for implementing a feasible and economical online BCI system, which may need a redundant number of EEG sensors and analysis. Thus, in order to implement a cost effective BCI system, we should reduce the number of EEG electrodes. Thus, we need careful consideration to decide the location of each EEG sensors as well as the reference electrode location. Until now, however, there has been little study addressing this problem, especially for the location of reference electrode. In this paper, we intend to find the optimal location of the reference EEG sensor in order to implement a BCI system with a higher level of performance. In our study, we use the imagination of left and right finger movement as the mental tasks. Ideally, the location of the reference electrode should be absolutely silent in electrical activity. However, in the case of scalp EEG, no location can meet the requirement, even the earlobe reference in the most of the unipolar paradigms. Those irrelevant noise components picked by the reference electrode make hard to extract a good EEG feature of interested mental states. In the case of classifying left/right hand motor imagery, if a reference location activates only when there exists motor imagery and its activity keeps stable, if not constant, across left and right imagery situations, it would be an optimal reference place to solely show the difference of two classes. In our research, we conducted the fMRI imaging to determine such an optimal location of the EEG reference electrode and the online BCI testing to verify it.

It is well known that fMRI equipment measures the blood oxygenation level dependant (BOLD) signal [2]. The BOLD signal is the level of oxygen consume that is by brain activity, according to a mental task. The EEG signal, however, is the local field potential (LFP) that reflects the electrical activity of neuron ensembles in the brain [2, 3, 4]. Thus, the physical property of data is different. There are, however, many studies which report that the BOLD signal and the cortical local field potential (LFP) have an almost linear relation [2, 3, 4]. The physical property of the LFP is the same as that of the scalp-EEG. The LFP signal can be transformed when it passes through the cortex, the cerebrospinal fluid (CSF), skull and scalp. Resultantly, fMRI experimental data may have a relationship with the EEG signals [5]. In our case, the mental tasks to be considered is mainly related with cortical activities not deep inside, such as M1, which make it possible to determine the optimal EEG electrode locations according to the fMRI hotspots without regarding dipole direction [6].

In Section II, the fMRI experiment is described together with the data analysis to find a candidate location for the EEG reference electrode. In Section III, we verify the estimation of the location of reference EEG electrode through online BCI experiment. Section IV describes the conclusion and our further research.

Manuscript received March 28, 2006. This work was supported by the Korea Research Foundation Grant funded by the Korea Government (MOEHRD)(KRF-2005-202-D00459) and National Natural Science Foundation of China under Grant 60205003.

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II. F REFERENCE EEG ELECTRODE

A. fMRI Experiment

The fMRI experiment was conducted with the cooperation of Brain Science Research Center (BSRC) in the Korea Advanced Institute of Science & Technology (KAIST). The experiments were conducted monthly in, 2005, and each experiment included two or three subjects. Among the eight subjects, one subject (subject A) participated in every experiment. The fMRI equipment included a 3T magnetic system. We set the time-to-repletion (TR) to 3000ms and the time-to-echo (TE) to 35ms. The motor imagery tasks were cued through the LCD project on the RF coil inside the gantry.

The subjects performed the mental task of left and right finger movement imagination. The fMRI experiment paradigm consisted of condition state time for 12sec and a resting state time for 24sec. The repetitive mental tasks were repeated six times for each session. We analyzed the data by using Statistical Parametric Mapping (SPM) toolbox (FIL, London, England). From this experiment and analysis, we were able to observe the brain activation area with respect to finger movement imagination mental task compared with that of a resting state.

B. fMRI Data Analysis for Seeking Candidate Reference Location

We first check whether the observed data of same mental task have similarities across different subjects and across different experimental periods.

After observing the data, we could determine clearly the brain activity in the supplementary motor area (SMA) in both left and right motor imagery cases. Figs. 1 and 2 show five months' data of subject A. Fig. 2 show the SPM analysis results of left finger movement imagination experiment of each period from May to November. Fig. 3 shows the SPM analysis results of right finger movement imagination experiment of each time period. First line of each figure indicates the right cerebral hemisphere activation and second line shows the left cerebral hemisphere activation. The last line shows the dorsal view of the cortex activation. The SMA area is in the secondary motor cortex area, which plays an important role in planning body movements [7, 8, 9]. Furthermore, as shown in Figs. 2 and 3, the activation area near the SMA has clear localization and activation features. The data analysis results obtained from other subjects also show these SMA activation features clearly. Using these observations, we can conclude that the SMA area is always activated whenever subject performing imagery tasks. For the reason we stated in previous section, the SMA area is most likely to be the optimal reference location of BCI system in which mental tasks include imagination of left and right finger movements.

Moreover, it is interesting to note that there are no prominent hotspots in the M1 area (which supposed to be involved in the real movement) for both imaginations of right and left finger movements. Moreover, it is difficult to find significant contralateral characteristics regarding the mental tasks in our experiment. These findings are consistent with those in other studies [9].

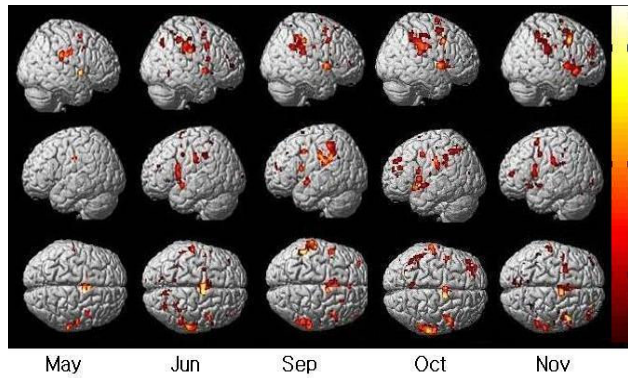

Fig. 1. The fMRI imaging result of left finger movement imagination experiment

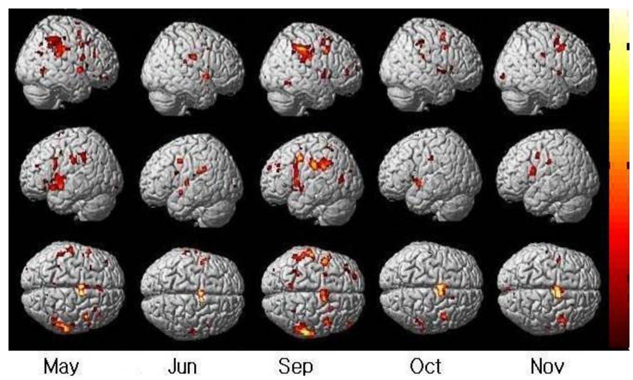

Fig. 2. The fMRI imaging result of right finger movement imagination experiment

III. EEG EXPERIMENTS TO VERIFY THE LOCATION OF THE REFERENCE ELECTRODES

A. EEG Experiment

From the fMRI experiment and analysis, we set the SMA area to a candidate location for activity reference instead of earlobe. To verify this estimation, we performed an EEG test. The EEG data were recorded in Tsinghua University, Beijing, China, by a 128-channel BioSemi ActiveTwo system (BioSemi, Amsterdam, Netherland) with a sampling rate of 256Hz. Only a subset (as shown in Fig.3) of the 128 electrodes was used. The point of grey color indicates the location where we measured the EEG signal. The indexing characters of each position are different that of 10-20 electrode system. But this system is based on polar coordination, we can match this indexing to 10-20 EEG electrode coordination (ex, FCz=C23, Cz =A1, C3=D19, C4=B22).

We conducted the EEG experiment in both online feedback mode and no-feedback mode. In the no-feedback mode, we set the experiment paradigm to same one with the fMRI experiment to make similar conditions for both cases. From this test we could compare the EEG activation of conditioning

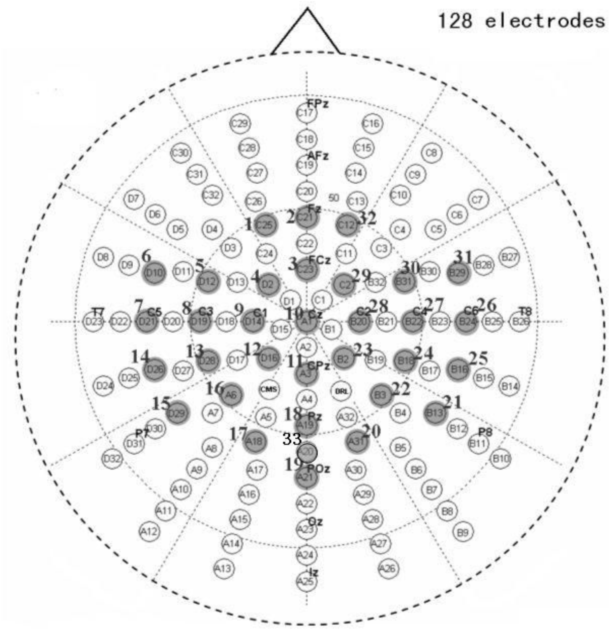

Fig. 3 Electrode placement in BioSemi 128-channel cap. Electrodes in grey color were used for the experiment.

state with that of resting state. The time duration for condition and resting states were set to 12 sec and 3 sec, respectively, and the session were repeated for 10 times.

The online feedback testing consisted of 60 trials of cursor control test per session. The experiment paradigm is similar to that described in [11]. The subject sat comfortably in an armchair, opposite to a computer screen for displaying the visual feedback. The duration of each trial was 8 seconds. During the first 2 seconds, while the screen was blank, the subject was in the "relax" state. Then, the screen cursor was controlled to move in two directions (up and down) and the update of the vertical position of the cursor was determined by mu rhythm power induced by user's left and right finger movement imagination. The target direction of each trial was in a random order of up and down. To provide the online visual feedback in real time, our system used only two bipolar channels data (C3-Fcz, C4-Fcz). The EEG features was the band power of mu rhythm (11Hz ~ 14Hz for one of the subjects). It is known that mu rhythm is usually recorded from the motor cortex of the dominant hemisphere. So we classified two classes (left or right finger movement imagination) with just mu power difference of C3-Fcz and C4-Fcz channels.

B. EEG Data Analysis and Verification of the Location for Reference Electrode

The EEG feature we regarded for offline analysis was also band power of mu rhythm (11Hz ~ 14Hz). In the offline data analysis of no-feedback experiment, we investigated the significance of the feature by the t-test between the condition state like finger movement imagination and the resting state [10]. Using the t-test, we can compare the difference in the EEG mu power between the condition state and the resting state. Eq. (1) shows the t-test. The numerator indicates the differences in average feature of the condition and resting states. The denominator term is the total variance of each state, in which Sw_1 and Sw_2 denotes the standard deviation of two sample groups, n_1 and n_2 denotes the number of sample in each group.

$$t = \frac{\overline{X_2} - \overline{X_1}}{\sqrt{\frac{s_{W1}^2}{n_1} + \frac{s_{W2}^2}{n_2}}} \qquad (1)$$

Table I and II show the results of the t-test analysis of the EEG data from the left and right finger movement experiments, respectively. Electrode positions D19 (C3), D28, D26 were located in the left hemisphere, and B22 (C4), B18, B16 were located in the right hemisphere. As can be seen from these tables, largest t-test level exists in the line of the C23 (FCz). Thus, it was confirmed that electrode FCz (in SMA) was the best reference of both left and right finger movement imagination. The t-test level of C21 (Fz) and A1 (Cz) reference was close to that of FCz. These tables also indicate that the t-test level of the contralateral electrodes highly depends on the reference electrode selection, while the reference electrode position does not have much effect on the t-test level of the ipsilateral electrodes. For example, t-test level of the B22 (C4) area ranges from 0.17 to 0.60 in the case of left (contralateral side) finger movement imagination, while it only ranges from 0.36 to 0.49 in the case of right (ipsilateral side) finger movement imagination.

In the online test with visual feedback, each session consists of 30 trials of left finger movement imagination and 30 trials of right finger movement imagination and 5 sessions were conducted. In the data analysis of feedback sessions, we consider the total hit rate performance. The average of the total hit rates for left and right imagery is used as overall hit rate performance. The performance of the hit rates were compared with respect to different reference electrode, such as C21 (Fz), C23 (FCz), A1 (Cz), A3 (CPz), A19 (Pz) and A21 (POz). Using those reference locations, we compared the hit rate performance between bilateral pair of electrodes as D19(C3)-B22(C4). Fig. 4 shows the hit rate performance using different locations of reference electrode. The x-axis represents different bilateral electrode pairs that gave relatively large power difference of mu rhythm. As shown in this figure, the hit rate of the data is about 93% when the reference electrode is selected as C21 (Fz) using the D19(C3)-B22(C4) pairs. The SMA area is near C23 (FCz), and the performance of FCz is almost the same as that of Fz. For other reference electrode, the hit rate is poor.

From the data analysis of feedback and non-feedback experiment, we can see that the location of reference electrode is very crucial for classifying left and right motor imagery EEG, and the SMA electrodes may act as the best reference electrode for picking up most useful differential EEG components between bilateral motor cortex activities in not deep cortex area during left and right finger movement imaginations.

TABLE I
T-TEST LEVEL OF EEG DATA FROM THE LEFT FINGER MOVEMENT EXPERIMENT WITH DIFFERENT LOCATION OF ELECTRODE AND REFERENCE

REFERENCE ELECTRODE	D19 (C3)	D28	D26	B22 (C4)	B18	B16
C21(Fz)	0.43	0.46	0.37	0.60	0.63	0.63
C23(FCz)	0.47	0.50	0.41	0.64	0.67	0.64
A1(Cp)	0.45	0.50	0.33	0.59	0.64	0.60
A3(CPz)	0.38	0.45	0.23	0.50	0.59	0.56
A19(Pz)	0.38	0.46	0.28	0.29	0.49	0.50
A20	0.36	0.46	0.29	0.19	0.41	0.43
A21(POz)	0.31	0.40	0.25	0.17	0.38	0.41

TABLE II
T-TEST LEVEL OF EEG DATA FROM THE RIGHT FINGER MOVEMENT EXPERIMENT WITH DIFFERENT LOCATION OF ELECTRODE AND REFERENCE

REFERENCE ELECTRODE	D19 (C3)	D28	D26	B22 (C4)	B18	B16
C21(Fz)	0.67	0.65	0.62	0.49	0.52	0.49
C23(FCz)	0.73	0.71	0.69	0.51	0.56	0.51
A1(Cp)	0.66	0.66	0.60	0.50	0.52	0.49
A3(CPz)	0.49	0.53	0.40	0.40	0.45	0.43
A19(Pz)	0.42	0.45	0.40	0.40	0.49	0.46
A20	0.40	0.42	0.37	0.37	0.48	0.44
A21(POz)	0.44	0.46	0.36	0.36	0.49	0.45

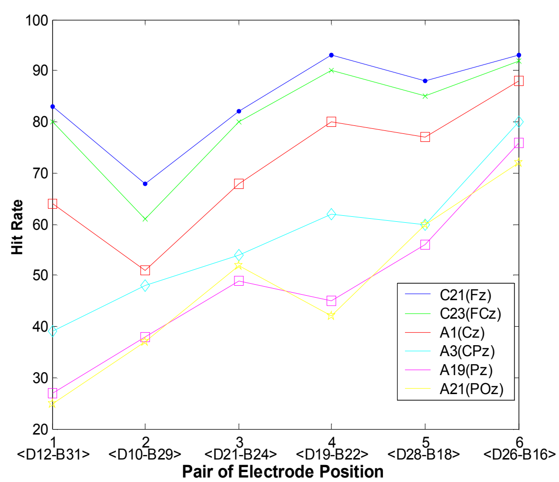

Fig.4. Hit rate performance with different location of reference

IV. CONCLUSION

In this paper, we suggested the SMA as the optimal reference location for the BCI system based on imaging finger movements, which were found by the fMRI experiment and tested with the EEG based BCI system. We carefully mentioned that the proposed neurophysiological approach is highly necessary in order to improve the performance of the conventional BCI system, and also the fMRI experiments may be able to give a good chance to get a reasonable answer for unsolved questions in BCI system.

ACKNOWLEDGMENT

This work was supported by the Korea Research Foundation Grant funded by the Korea Government (MOEHRD). (KRF-2005-202-D00459).

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