A New Computational Method for Single-Trial-EEG-Based BCI

Proposal of the Number of Electrodes

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Abstract. In this paper, the categorization of single-trial EEG data recorded during the MI-related task, as another data reduction, will be attempted, because the categorical data would require less storage and computational time than continuous one. The categorization will be realized by equivalent current dipole source localization (ECDL). To analyze this, we used EEG data and visually evoked related potentials (v-ERP) led by 32 electrodes. From the result of single-trial v-ERP, only 6 electrode v-ERPs have a remarkable reaction. Therefore, from the view point of business, it is found that the minimum number of electrodes have been seven.

Keywords: EEG, Brain Computer Interface, equivalent current dipole source localization, topography.

1 Introduction

In non-invasive Brain-Computer Interfaces (BCIs), scalp-recorded-electroence-phalo gram (EEG)-based BCIs with motor imagery (MI) have extensively progressed in the past two decades [1]. Such BCIs consist of feature extraction and classification using the features. Most of the BCIs utilize the sensorimotor rhythmic (SMR) features. These features could be extracted from event-related desynchronization (ERD) and synchronization (ERS) in mu, beta and gamma rhythms over the SM cortex during MI tasks [2], [3], [4], as well as actual movement ones [4], [5], [6]. The features over these broad frequency bands require multi-channel EEGs of more than 1 s. Moreover, very high-dimensional feature vectors and continuous-valued patterns are necessary for spatiotemporally checking the features (e.g., [7], [8], hence yield an enormous amount of data and much computational time (e.g., [9]. Therefore, various data reductions such as downsampling [10], [11], [12] and optimal EEG channel configurations [13], [14].

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This study was motivated by another data reduction and non-rhythmic characterization of ERD and ERS in the BCIs, one of whose solutions could be multiple equivalent current dipole source localization (mECDL) with independent component analysis (ICA). There had been already a few of the former approaches to the BCIs [15], [16], [17], [18]. However, the first three studies had limited to one- or two-dipole, and the fourth one had not led to data reduction, because four hundred dipoles were estimated. The ICA methods are now widely used for separating artifacts from scalp-recorded EEG and related data [19], [20], [21], and have been already practiced in EEG-based BCIs [8], [22], [23].

In this paper, the categorization of single-trial EEG data recorded during the MI-related task, as another data reduction, will be attempted, because the categorical data would require less storage and computational time than continuous one. The categorization will be realized by equivalent current dipole source localization (ECDL). Some of the authors had already found the parietal and premotor cortices as the neural correlates for the MI from the multiple ECDL using the averaged EEGs [24]. Moreover, from our event-related functional magnetic resonance imaging (ERfMRI) study [25], it followed that the MI activated the superior and inferior frontal gyri, the pre- and post-central gyri and the superior and inferior parietal lobuli. These findings will be incorporated into Hayashi's second method of quantification which could quantify categorical data consisting of samples, items and categories (features) (hereafter, this method is abbreviated to H2MQ) mentioned below. In order to separate scalp-recorded EEGs into functionally independent sources, including neural components originating from different brain areas and artifact components attributed to eye movement, blinks, muscle, heart and line noise [23], ICA will be applied to the EEG data, then the ECDL with one dipole to reconstructed EEG from each IC corresponding to only neural activity by the deflation procedure.

2 Experiments

2.1 Subjects

Ten healthy male subjects between the ages of 22 and 35 (mean age 28.7years; SD 4.12) participated in this experiment. All the subjects were right handed according to the Edinburgh Inventory[26].

2.2 Experimental Protocol

Subjects were seated inside an electrically shielded room with sound attenuation, and gazed at a monochromatic monitor of an AV tachistscope (IS-701B, IWATSU ISEL) 0.9 m away from their eyes. They were requested to relax their both hands on a table and with their chins on a chinrest (Fig.1). In the present experiment, three kinds of line drawings of hands were presented on the monitor: (1) right-hand stimulus to imagine being shaken with the subject's right hand, (2) left-hand one for the subject's left hand imagery and (3) open-right-hand one as control (Fig.2). These stimuli

were sequentially and randomly presented with probabilities of 0.20, 0.20 and 0.60, respectively. Among all the stimulus conditions, the following two kinds of trials were chosen for data analysis. That is, the subject's task is to imagine grasping the right-hand stimulus with her or his own right hand as soon as possible when the stimulus was displayed (right-hand-movement imagery: RH-MI); one to image grasping the left-hand stimulus with her or his own when the stimulus was presented (left-hand-movement imagery: LH-MI). Both hands were hidden under a black coverlet so that it is easier for the subjects to imagine the hand movement. There was a short training session during which the subjects' hands were not covered with the coverlet. One test session includes the two conditions with a five-minute break between the conditions, where each condition contains 130, 130 and 400 trials for the above (1), (2) and (3), respectively. Therefore, it took about 45 minutes to finish one session. Note that different subject had different order of the conditions.

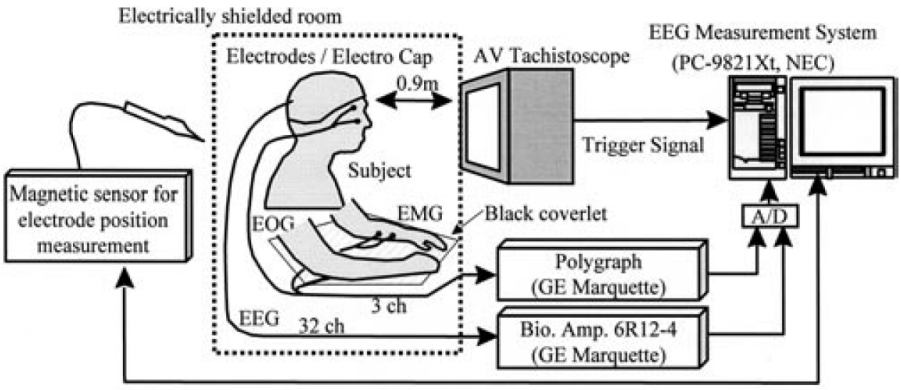

Fig. 1. Experimental system for the measurements of EEG, EOG, EMG and electrode positions and for stimulus presentation [28]

2.3 Electrophysiological Recordings

With an electro cap (ECI, Electrocap International), EEG was recorded from 32 electrodes (FP1, FPz, FP3, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T3, C3, Cz, C4, T4, CP5, CP1, CPz, CP2, CP6, T5, P3, Pz, P4, T6, PO3, POz, PO4, O1, Oz, O2) at scalp positions that were defined on the basis of the International 10-20 System [27]. All the electrodes were referred to A1, the ground electrode was attached to FPz and their impedances were kept below 5kΩ. Vertical and horizontal eye movements were monitored with two electrodes placed directly above the nasion and the outer canthus of the right eye. Another two electrodes were placed at both the medial antibrachiums to record arm electromyogram (EMG) so that EEGs could be excluded from the average when mistakenly grasping during the movement imagery.

The 32 signals of the EEGs were amplified by a Biotop 6R12-4 amplifier (GE Marquette Medical Systems Japan, Ltd.), and filtered in a frequency bandwidth of 0.01-100 Hz. The amplified signals were sampled at a rate of 1 kHz during an epoch of 100 ms preceding and 700 ms following the stimulus onset. The inter-stimulus interval was 1600 ms (figure 3). The on-line A/D converted EEG signals were immediately stored on a hard disk in a PC-9821Xt personal computer (PC) (NEC Corporation). The EOG and EMG data was also amplified by a Polygraph 360 amplifier (GE Marquette Medical Systems Japan, Ltd.), and sent to the same PC.

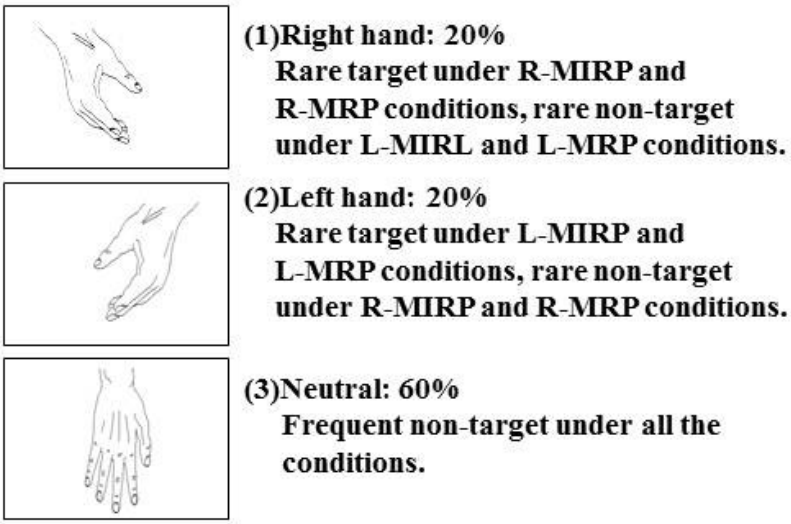

Fig. 2. Stimulus contents

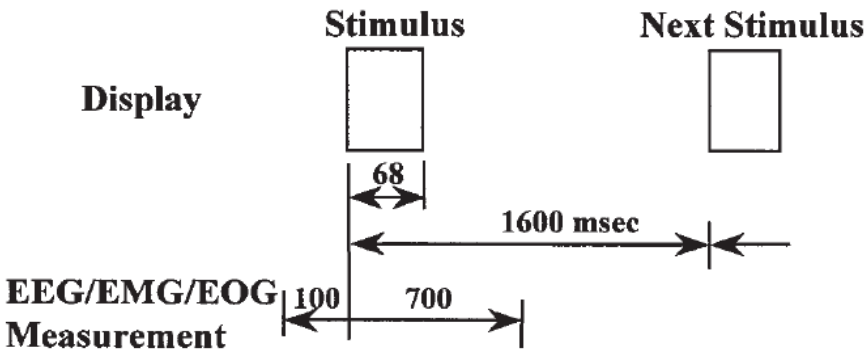

Fig. 3. Time-scheduling of the stimulus presentation and the measurements of EEG, EOG and EMG

3 Results

Figures 4a and b show the rare target and non-target 32-channel grand average ERP waveforms from all the ten subjects under the L-and R-MIRP conditions, respectively. Scalp topographic maps of 16 instantaneous timepoints, N200 at 200 ms, 200 ms, 200 ms and 200 ms, respectively, P280 at 280 ms, 271 ms, 280 ms and 271 ms, respectively, early P300 (P3e) at 333 ms, 333 ms, 338 ms and 323 ms, respectively, and late P300 (P3l) at 376 ms, 376 ms, 376 ms and 359 ms, respectively, for the rare target and non-target under the L-MIRP condition and for those under the R-MIRP condition, are shown in figure 5. From a preliminary experiment of 9 ch MIRPs (Kamijo et al. 1997), it was suggested that the N200 might be RP-like components, and that the P280 and P3e are similar to RAP (reafferent positivity)-like components.

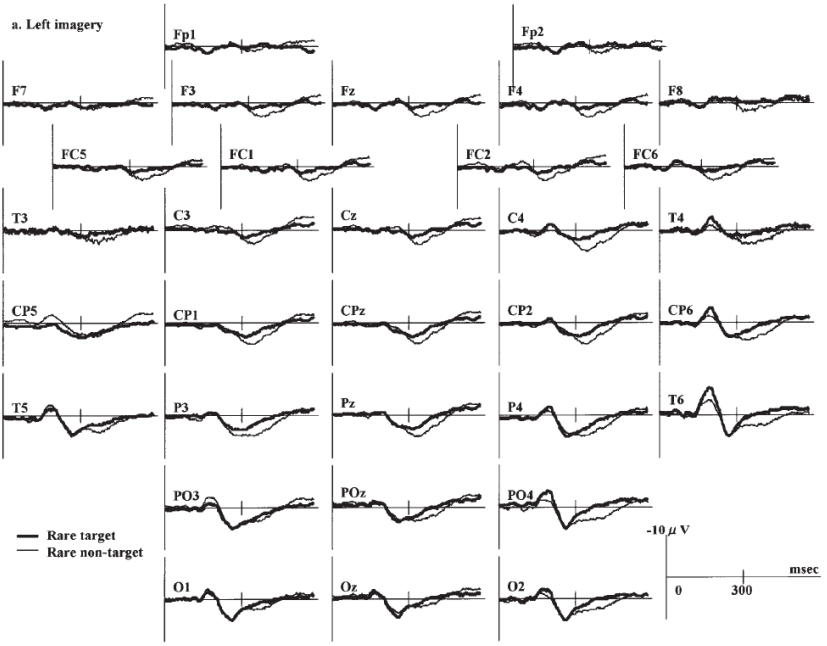

Fig. 4. a. L-MIRP condition of 32 channels of left mastoid referenced ERP, overlapping the waveform to the rare targets and that to the rare non-targets, depicted by thick and thin lines, respectively [28]

4 Discussion

Kamijo, et al. tried to show a difference of visual ERPs during movement imagery tasks between the condition of 9 scalp electrodes and 32 electrodes[28]. From this, in case of 9 electrodes, movement imagery might involve partially the same neural

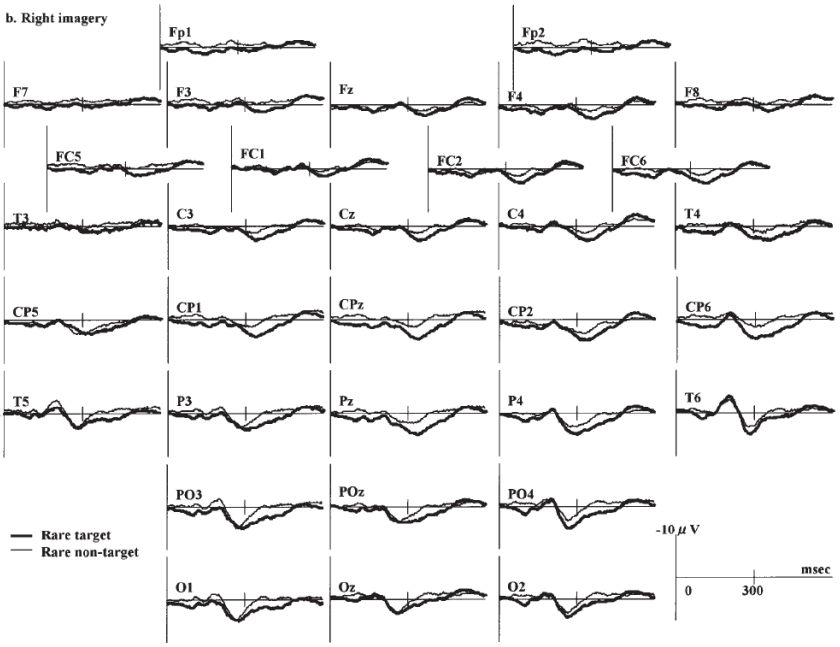

Fig. 5. b. R-MIRP condition of 32 channels of left mastoid referenced ERP, overlapping the waveform to the rare targets and that to the rare non-targets, depicted by thick and thin lines, respectively [28]

structures as during actual movement. In case of 32 electrodes, existence of early components and late components in P300s was shown. On the other hands, in the view point of silent speech, Yamamoto et al. succeeded to correspond images of "rock", "paper" and "scissors" to silent speech of them by using single-trial EEGs of 19 electrodes[29]. In that time, ICA and ECDL were also used as analysis methods. However, considering this technology applying to business area, a brief measurement method by a few electrodes is necessary.

This time, we used 32 electrodes on scalp. From ERP data shown in Figure 4a and 4b, the response of 6 electrodes, they are "CP5", "CP6", "T5", "T6", "PO3" and "PO4", are found to be remarkable for both case. Thus, the feature change in potential data led by remaining 26 electrodes was not found. From this, 26 electrodes' data could be considered same. By giving any one electrode data on 26 to the other 25 electrodes and using responded six electrodes data, we can deal with totally 32 channel data. Therefore, this result shows the possibility to estimate movement imagery by using seven electrodes.

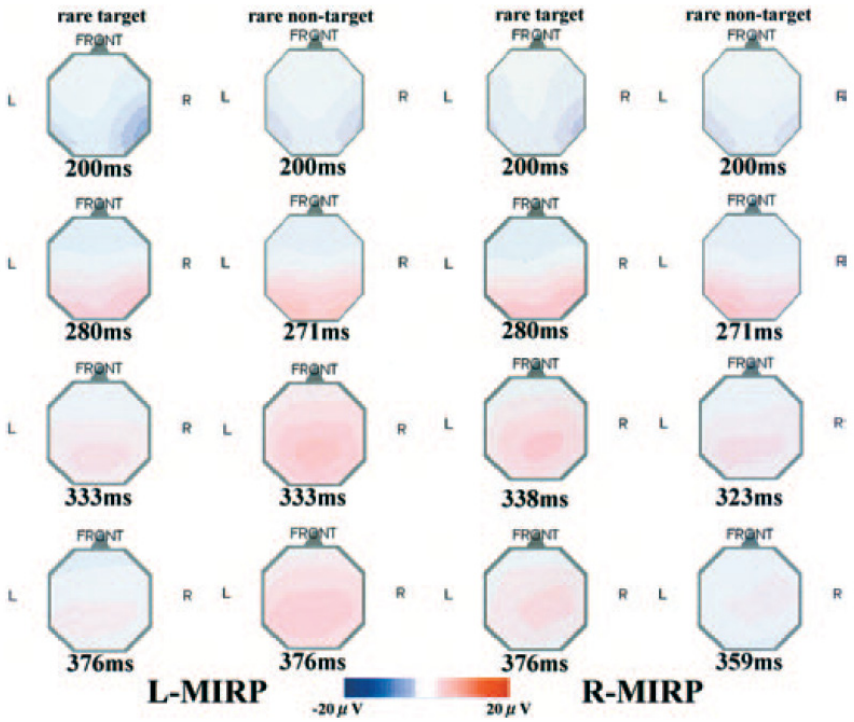

Fig. 6. Topographic maps of the N200, P280, P3e and P3l for the rare target under the L-MIRP condition (1st column); those for the rare non-target under the L-MIRP condition (2nd column); those for the rare target under the R-MIRP condition (3rd column); those for the rare non-target under the R-MIRP condition (4th column) [28]

5 Conclusion

This study was undertaken to record visual ERPs during movement imagery for right-handed subjects, and to investigate the temporal aspects of the neural structures involved in movement imagery. From this, we found that the response of seven electrodes, they are “CP5”, “CP6”, “T5”, “T6”, “PO3” , “PO4”, and any one of remaining 26 electrodes are found to be remarkable. Thus, we suggest that we can extract characteristics of visual ERPs using our proposal analysis method.

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