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Applicability of the "Emotiv EEG Neuroheadset" as a User-friendly Input Interface

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Abstract— **We aimed to develop an input interface by using the P3 component of visual event-related potentials (ERPs). When using electroencephalography (EEG) in daily applications, coping with ocular-motor artifacts and ensuring that the equipment is user-friendly are both important. To address the first issue, we applied a previously proposed method that applies an unmixing matrix to acquire independent components (ICs) obtained from another dataset. For the second issue, we introduced a 14-channel EEG commercial headset called the "Emotiv EEG Neuroheadset." An advantage of the Emotiv headset is that users can put it on by themselves within 1 min without any specific skills. However, only a few studies have investigated whether EEG and ERP signals are accurately measured by Emotiv. Additionally, no electrodes of the Emotiv headset are located over the centroparietal area of the head where P3 components are reported to show large amplitudes. Therefore, we first demonstrated that the P3 components obtained by the headset and by commercial plate electrodes and a multipurpose bioelectric amplifier during an oddball task were comparable. Next, we confirmed that eye-blink and ocular movement components could be decomposed by independent component analysis (ICA) using the 14-channel signals measured by the headset. We also demonstrated that artifacts could be removed with an unmixing matrix, as long as the matrix was obtained from the same person, even if they were measured on different days. Finally, we confirmed that the fluctuation of the sampling frequency of the Emotiv headset was not a major problem.**

I. Introduction

The goal of our research was the development of an input interface that utilizes the P3 component of visual event-related potentials (ERPs). We sought to develop an interface that is convenient and easy to use for patients with amyotrophic lateral sclerosis (ALS), healthy people whose hands are occupied, and those for whom the use of sound input is not feasible depending on the environment.

When using electroencephalography (EEG) in daily applications, it is especially important that the interface is able to cope with artifacts caused by eye movements and blinking and to provide a means to easily attach electrodes. We previously proposed a method for removing ocular artifacts by using independent component analysis (ICA). The convergence time required for ICA oftentimes becomes problematic for real-time processing. Therefore, our proposed method does not directly apply ICA to the target data; instead, it applies an unmixing matrix and its inverse matrix that have been obtained previously using another dataset after removing rows and columns corresponding to ocular movement components. This method is based on the hypothesis that the unmixing matrix provided by ICA does not change significantly if electrode placement remains the same, which has been confirmed by experimental data [1].

Here, we introduce the "Emotiv EEG Neuroheadset," which is a commercial-type, 14-channel headset (14 plus 2 reference electrodes). Using this headset, users can easily place electrodes on nearly the same locations across different sessions. Applications for this device in gaming or character input interfaces are growing; however, only a few studies have investigated whether EEG and ERP signals are measured correctly with this device.

Ekanayake [2] measured the P3 components of visual ERPs with the Emotiv using the P3 Speller paradigm. They obtained clear ERP P3 components, demonstrating that the Emotiv does capture actual EEG signals. Hariston et al [3] compared four different commercially available EEG systems (three wireless systems, including Emotiv and one traditional wire-based system) and focused on jitter, or variability, of trigger timing. They found that Emotiv showed the largest jitter, which resulted in unclear ERP waveforms. Perieau et al [4] compared the performance of a 2 × 2 P300-Speller between a medical/research EEG device and the Emotiv in two conditions (sitting and walking) for seven participants and found that the performance of the Emotiv headset was worse in both. However, the ratio of correct answers averaged for the seven participants was more than 80%.

In the abovementioned studies, EEG signals were not compared with the Emotiv recordings using simultaneous measurement with a bioelectric amplifier. The amplitude of the P3 components of EEG signals varies greatly across different locations on the scalp, and the electrodes of the Emotiv headset are not located on the centroparietal area of the head where P3 components are largest. This may pose a problem for detecting P3 signals using this device.

To test whether P3 components comparable to those measured with commercial plate electrodes could be obtained using the Emotiv, we performed an experiment using an oddball task and compared the P3 components obtained by the headset with those measured by commercial plate electrodes and a multi-purpose bioelectric amplifier. The proposed method for removing ocular artifacts was validated by using the EEG data from four to six channels based on the International 10-20 system. Therefore, it was necessary to confirm that the proposed method could be applied to Emotiv-obtained 14-channel EEG data. An experiment was planned to confirm that the removal of artifacts with an unmixing matrix is possible when the matrix is obtained from

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the same participant's data, even if the measurements occurred on different days.

II. METHOD

The experiments reported in this paper were executed with the permission of the president of Osaka Institute of Technology in accordance with the report of the Ethics Committee on Life Sciences of Osaka Institute of Technology.

A. Participants

The participants were five healthy male undergraduate students who provided written informed consent to participate.

B. Measurement

We recorded EEG signals using the 14-channel Emotiv headset, the locations of which are shown in Fig. 1. Fourteen electrodes were placed on the AF3, AF4, F7, F8, F3, F4, FC5, FC6, T7, T8, P7, P8, O1, and O2 based on the International 10-20 system. Two more reference electrodes (CMS/DRL) were placed on P3/P4.

The Emotiv parameters were set as follows: time constant, 0.8 s; low-pass filter cut-off frequency, 45 Hz; sampling frequency, 128 Hz.

For comparison, two channels of the EEG were measured using the commercial plate electrodes and a multi-purpose bioelectric amplifier (BA1008m, DIGITEX LAB.Co.,LTD). The plate electrodes were placed on Fz and Cz based on the International 10-20 system. Horizontal and vertical electro-oculogram (EOG) signals were measured using the same instruments so that the independent components (ICs) related to ocular movement could be identified. The acquired EEG signals were sampled at 1,024 Hz after being amplified with sensitivity of 20 μV/0.5 V and a time constant of 1.5 s. Fig. 2 shows a participant wearing the Emotiv headset.

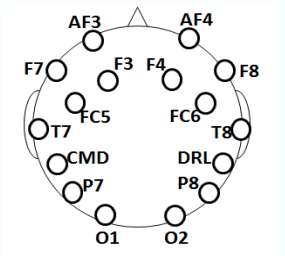

Fig. 1. Emotiv headset electrode locations.

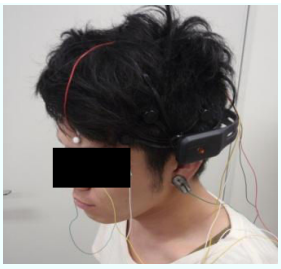

Fig. 2. Emotiv worn on the head.

C. Protocol

Participants were required to put the Emotiv headset on by themselves according to written instructions. Felt pads moistened with saline solution were used to increase conductivity between the electrodes and the scalp. One can put on the headset within approximately 1 min without any prior training.

Next, a dataset for calculating the unmixing matrix was collected. This was composed of an eye movement session and an oddball task session. To cause horizontal and vertical ocular movement, participants were instructed to look at one of four numbers arranged in the right, left, upper, and lower sides of the display that flashed in turn. After acquiring the eye movement data, we acquired data contaminated with eye blinks. Participants were required to blink when they saw a word instructing "eye-blink" flashes. Flash intervals in ocular movement and eye-blink sessions were 500 ms, and a 5-s break was given between the two sessions. In the oddball session, 200 stimuli composed of either backward "C"s (target) or normal "C"s (non-target) in a ratio of 2:8 were presented at a 1000 ms stimulus interval. The participants were required to count target stimuli.

In total, six datasets were obtained for each participant. Three datasets were collected on the first day, and three were collected on another day.

III. ANALYSIS

A. Obtaining P3 components with Emotiv

During the oddball session, the EEG signals for each trial were extracted from the -0.2 to 1 s epoch around every trigger by setting a trigger point at each stimuli onset. A baseline correction was performed using the averaged signal value for a 0.2 s duration just before the trigger point. The trials with EOG data greater than ±100 μV were removed from averaging.

EEG signals obtained from commercial plate electrodes were down-sampled from 1024 Hz to 128 Hz. The reference electrodes for Fz and Cz were placed on the left and right earlobes, respectively. No Emotiv electrode was located on the centroparietal area of the head where P3 components are reported to show larger amplitudes. Therefore, the P3 component was obtained by averaging EEG signals over six channels (F3, F4, T7, T8, P7, and P8) surrounding the centroparietal area.

B. Decomposition and removal of components related to eye blinks and ocular movements by ICA

To apply ICA to an EEG dataset, an unmixing matrix and ICs were obtained. Among the components, those showing large coefficients of correlation with horizontal eye movements, vertical eye movements, and eye blinks during the eye movement session were identified. From this data, the inverse matrix of the unmixing matrix was calculated. After filling all elements in the rows of the inverse matrix corresponding to the identified artifact components with zeros, it was applied to the target EEG dataset. Artifact-free EEG signals were obtained using this method.

The degree of residual artifactual components was estimated by the coefficients of correlation between EOG (using h-EOG during horizontal eye movements and using v-EOG during vertical ones and blinks), and EEG signals from each Emotiv electrode during the eye movement session.

In the last procedure, three types of the applied dataset were introduced. The degrees of residual artifact components were compared among the three methods. The first dataset was the original EEG dataset, which was used to obtain the unmixing matrix. The second dataset was recorded on the same day without removing or replacing the headset, and the third dataset was obtained from the same participant on a different day. The headset was mounted the same way on both 2 days.

C. *Comparison of P3 components between different removal methods for ocular artifacts*

To confirm the effectiveness of the proposed method for artifact removal, the third dataset mentioned in section B was averaged to obtain the P3 component via the method described in section A after processing with two artifact removal methods. One was the proposed method using the unmixing matrix derived from the dataset recorded on another day. In the other method, trials contaminated with eye movements or blinks were excluded from averaging; these were identified by EOG data using the threshold value of ±100 μV. The P3 components obtained by these two methods were compared for five participants.

IV. RESULTS

A. *Measurement of P3 components with Emotiv*

Figure 3 shows the P3 components obtained from both plate electrodes (Fz and Cz) and the Emotiv headset in each of the five participants (A-E). Red and blue traces are the averaged EEGs for target and non-target stimuli, respectively. The averaged EEG forms obtained by Emotiv are not exactly same as those obtained from Fz and Cz, but they are similar.

The differences between the P3 components for the target and non-target stimuli are also observed in Emotiv data.

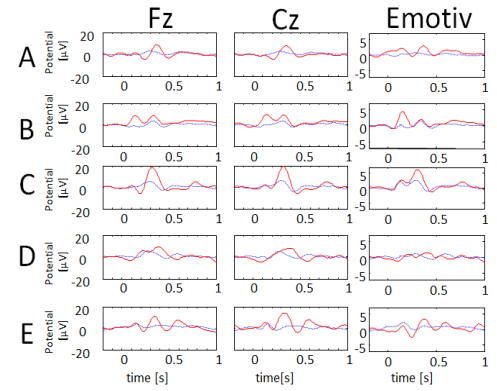

Fig. 3. P3 components obtained from plate electrodes (Fz and Cz) and Emotiv in 5 participants (A-E).

B. *Decomposition and removal of components related to eye blinks and ocular movements by ICA*

Fig. 4 shows the degree of residual artifact components evaluated by the coefficients of correlation between EOG and EEG signals from each Emotiv electrode location in each eye movement session.

The second column shows the results for the first proposed analysis method mentioned in section III. Artifact removal was executed by applying ICA to the dataset. The coefficients of correlation between EOGs and EEGs after artifact removal were very small. As shown in the third column, the second type of proposed analysis method also produced successful results. That is, the proposed method using ICA for artifact removal is effective even if the unmixing matrix was derived from other data.

For the third type of correction (unmixing matrix applied to the dataset of another day with headset refitting), the coefficients of correlation were slightly higher at a few locations. However, the artifact components are reduced significantly compared to the raw data.

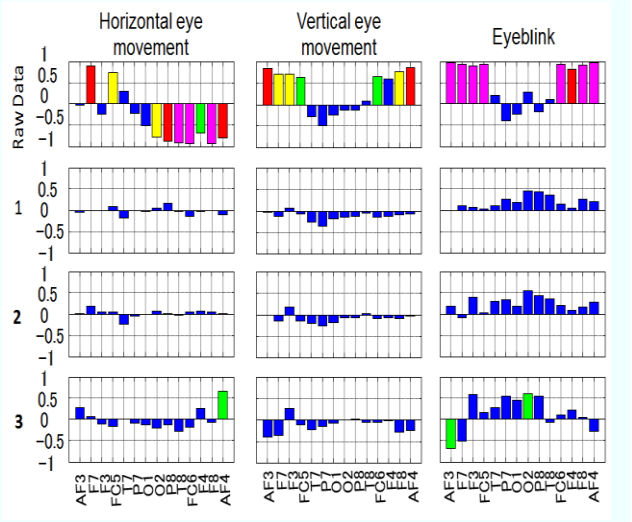

Fig. 4. Comparison of the artifact removal methods with regard to the degree of residual artifact components as evaluated by the correlation coefficients between EOGs and EEGs. See text for details.

These results are summarized in Fig. 5 to compare the effectiveness of the three types of artifact removal applications. The bar denotes the ratio of pairs of EOGs and EEGs that show small coefficients less than 0.5 (green), moderate ones between 0.5 to 0.6 (yellow), and large ones greater than 0.6 (red). The results for both datasets for the second type and three datasets for the third type are shown.

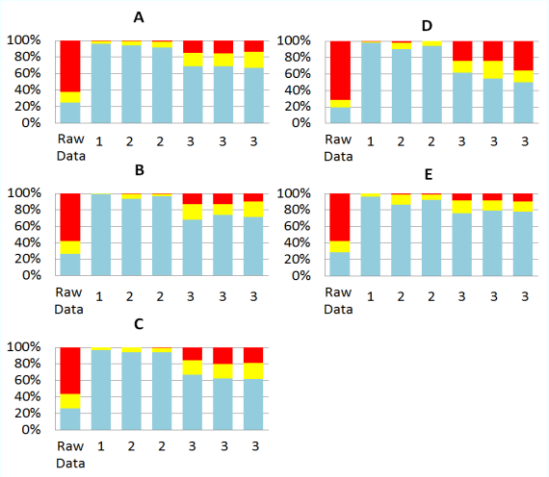

Fig. 5. The ratio of small (blue), moderate (yellow), and large (red) correlation coeficients between EOGs and EEGs (raw data, data applied by three kinds of artifact removal) for five participants (A-E).

C. *Comparison of P3 component between removal methods for ocular artifacts*

Fig. 6 shows the averaged EEGs triggered by non-target stimuli onset comparing before (blue) and after (red) artifact removal. The averaged waveforms had components similar to P3. However, those components disappeared after artifact removal. It is likely that those components were caused by blink artifacts because participants tend to blink at similar latencies following non-target stimuli.

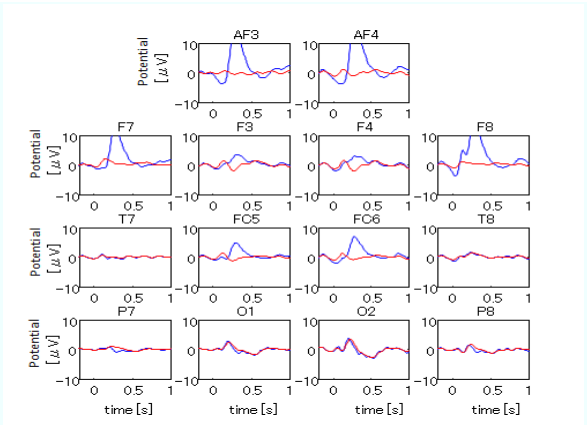

Fig. 6. Comparisons in the averaged EEGs before and after artifact removal.

Fig. 7 shows the differences between P3 components for target stimuli (red) and for non-target ones (blue). It also shows the comparison between the different methods for coping with ocular artifacts. The artifact components removed by our proposed method are shown with a solid line, and trials with EOG data larger than the ±100 V threshold value that were excluded from averaging are shown with a dotted line. The P3 components obtained (by both methods) are almost the same, which suggests that the proposed method of artifact removal does not remove too much and preserves the meaningful components of signals, such as P3.

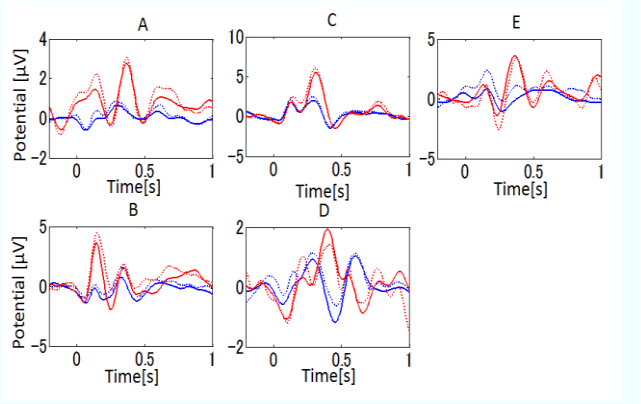

Fig. 7. Comparison of P3 components: solid line, the proposed method; dotted line, conventional method; red denotes target stimuli, blue denotes non-target stimuli.

V. PROBLEM OF TIME FLUCTUATION WITH THE EMOTIV SYSTEM

The real-time software development kit (SDK) for the Emotiv headset does not accept any external input, so it becomes problematic to obtain trigger signals for calculating ERP. In the offline analysis mentioned in previous sections, both EEG data measured by a bioelectric amplifier and stimulus signals made by photoreceptive sensors on the display were recorded on a PC via the same analog-to-digital (A/D) converter, and the stimulus signals were used as triggers for ERP calculation.

As reported by Hariston et al [3], time fluctuations of the Emotiv system were problematic. Therefore, for the offline analysis, we asked to participants to blink a few times at the beginning and end of the measurement session. The difference in the start points was detected and corrected by comparing eye-blink waveforms in EEG data from Fp3 of the Emotiv headset with those in vertical EOGs measured by the bioelectric amplifier. The end points were decided by a similar method, and the correction coefficient of sampling frequency for the Emotiv headset was calculated so that the measurement durations in both systems were equivalent. The EEG data obtained by the Emotiv were interpolated by the third-order spline function and re-sampled with a correct sampling frequency.

In this section, we report the result on time fluctuations of the Emotiv, expecting the situation in which ERPs may be obtained only by the Emotiv in approximately real time, without a bioelectric amplifier.

we confirmed that the fluctuation of the sampling frequency of the Emotiv headset. A triangle wave of frequency 10 Hz and amplitude 100 mV with the use of a function generator was entered directly to an A/D converter and collected with a sampling frequency of 128 Hz using the internal clock of the A/D converter (NI PCIe-6231, National Instruments). The signal was attenuated to 100 μV by resistors and administered to the electrode located at Fp3 of the Emotiv headset simultaneously. The two reference electrodes were grounded. These signals were recorded on separate PCs and compared afterward.

Ten 10-minute trials were performed. The start time differences and the sampling frequency were corrected so that the signal obtained by the Emotiv corresponded with that of the A/D converter. Assuming the sampling frequency of A/D converter is correct; the sampling frequencies of the Emotiv headset were estimated as 127.885 Hz for all 10 trials. After the sampling frequency was corrected, the peak time of the signals obtained by both systems was compared, and the differences were confirmed to be settled between ±1 samples (±1/128 s) for all triggers.

VI. CONCLUSION

We found that we were able to remove eye movement artifacts using an unmixing ICA matrix. The time fluctuation of the Emotiv allows the use of triggers made by another system with an independent clock for calculating ERPs. Future studies are necessary to validate the proposed method in real-time applications.

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