Feature Extraction for Finger Motor Imagery

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Abstract

In recent years, the studies on Brain Computer Interface (BCI) to manipulate computer using an electroencephalogram, not through devices such as keyboards and mice, have been actively conducted. The main purpose of such BCIs is to develop communication tools for handicapped users.

In this paper, we investigated differences among behaviors of Bereitschaftspotential (BP) which is one of components of movement-related cortical potentials (MRCPs), during the motor imagery of simple movements and complex movements of fingers. As a result, before and after training, some changes, such as integration or deletion, have been observed in the components related to voluntary movements, such as BP, etc. In addition, the inflow and outflow of information between Fpz and Cz have been confirmed to be reversed at intervals of 0.5 sec to 1 sec before each movement onset.

1. Introduction

In recent years, the studies on Brain Computer Interface (BCI) to manipulate computer using an electroencephalogram (EEG), not through devices such as keyboards and mice, have been actively conducted.

The BCI enables some handicapped users to operate some external devices by discriminating their intentions using the EEG signals. Hence, the central issue is to extract appropriate features from the EEG signals and correctly discriminate users' intentions. As typical characteristic EEG signals that are applied to such scenes, there are P300 and steady-state visual evoked potential (SSVEP). Furthermore, movement-related cortical potentials (MRCPs) exist: the slow negative EEG activity begins about 2 to 1 sec before the voluntary movement onset [5].

Beretschaftspotential (BP), one of components of the MRCPs, is considered to reflect the ready state for the voluntary movement. Therefore, if we can detect and identify the initial slow segment of the BP, we can identify the intentions before the voluntary movement onset. That leads us to improve the degrees of freedom and the usability of the BCI systems [1].

The purpose of this study is to develop a novel BCI system by utilizing the BP as the features. The main contribution of this paper is to investigate differences among behaviors of BP during the motor imagery of simple movements and complex movements of fingers.

2. Principle

2.1 Bereitschaftspotential (BP)

Bereitschaftspotential (BP) is one of components of MRCPs. The initial segment of BP has the slow negative EEG activity that begins about 2 to 1 sec before the voluntary movement onset as shown in Fig. 1. The amplitude of the readiness potential at Cz, which is the midline central electrode, is 2.0 to 3.5μV, gradient is 0.3 to 0.4μV / 100msec. Fig. 1 shows an example of waveform of the MRCP measured by using as the trigger the EMG signals that occurred at the voluntary movement onset.

Fig. 1. Example of waveform of MRCP [2].
2.2 Modified wavelet transform (MWT)

Time-frequency information about a signal can be obtained by a continuous wavelet transform. In this paper, Gabor function is utilized as the mother wavelet. Modified wavelet transform (MWT) [3] is to perform the wavelet transform by adjusting the damping coefficient $\sigma$ which defines the Gabor function. The time-frequency analysis by MWT can have suitable frequency resolution for analyzing frequency components of EEG.

In MWT, $\sigma$ is adjusted according to the scaling parameter $a$ as follows,

$$
\sigma = \sigma_{\text{min}} + \frac{K}{1 + \exp(-K_T(1/a - 1/a_c))},
$$  
(1)

where $\sigma_{\text{min}}, K, K_T, a_c$ are constants. In this paper, we have set $\sigma_{\text{min}} = 0.8$, $K = 10$, $K_T = 2.5$, $a_c = 0.1$.

2.3 Directed information analysis (DI)

Generally, when several time series are simultaneously observed from various electrodes of a subject, we can easily assume that there are some correlations among them. Hence, we can discover several causal relationships as correlations among the time series based on their time context [4].

The causal relationships among the time series are described by directed information. First, let us consider two time series $X$ and $Y$ with length $P + 1 + M$ as follows,

$$
X = x_{k-P} \cdots x_k x_{k+1} \cdots x_{k+M} = X^P X^M, \quad (2)
$$

$$
Y = y_{k-P} \cdots y_k y_{k+1} \cdots y_{k+M} = Y^P Y^M. \quad (3)
$$

Then, we can define the directed information as (4), where the arrows are used for clarifying the mutual information between $X$ and $Y$ with the direction of time.

$$
I( x_k \rightarrow Y^M | X^P Y^P y_k )
$$

$$
= \sum_{m=1}^{M} I( x_k \rightarrow y_{k+m} | X^P Y^P y_k ) \quad . \quad (4)
$$

We can interpret (4) as the amount of the information which occurred in $X$ at the time $k$ is transmitted to $Y$ with delay time of $m$ step. Assuming that the time series has Gaussian process, we can simply calculate the amount of the directed information as follows,

$$
I( x_k \rightarrow y_{k+m} | X^P Y^P y_k )
$$

$$
= \frac{1}{2} \log \frac{R( \begin{array}{c} x_k Y_k \\ y_{k+m} \end{array} )}{R( \begin{array}{c} x_k Y_k \\ Y_k \end{array} )} \quad (5)
$$

where $R(\cdots)$ denotes the covariance matrix. Since we set $P = 0$ in this paper, we can calculate the directed information by using only $x_k, y_k, y_{k+m}$.

3. Experiment Procedures

3.1 Experiment environment

In this experiment, we analyzed EEG signals measured from three healthy adult males between 21 and 23 years old. They participated in this experiment every two days. The all signals were recorded with sampling frequency 512Hz by g.USBamp (24 Bit biosignal amplification unit, g.tec Medical Engineering GmbH, Austria).

Fig. 2 shows the electrode position of the extended international 10-20 system. We measured a total of 23 channels at electrodes filled with color. They include C3 C4 and Cz which correspond to the motor area of the cerebral cortex, Fpz and Oz which locate in front and back of the head. Besides them, we select a total of 18 positions (Fp1, Fp2, AFz, Fz, FCz, FC3, FC4, C1, C2, C5, C6, CPz, CP3, CP4, Pz, POz, O1, O2) which are surrounded with their site.

Furthermore, two channels placed on the left foot were added as trigger signals to confirm the onset of the motor imagery.

3.2 Subject’s tasks

In this experiment, since the purpose is to measure the EEG signals which correspond to the voluntary movement, neither presented instructions nor an external stimulus are given to the subjects. We have the subjects perform actions of four patterns (behavior patterns) as shown in Table 1, using the fingers of the right hand. The terminology for each action is defined as follows.

- "Motion": Moving the fingers actually
- "Motor Imagination": Imagining the movement of the hand without moving actually
- "Simple motion": Performing grasp motion with all five fingers
- "Complex motion": Attaching the thumb one by one in order from the index finger to the little finger
Table. 1. Behavior patterns of subjects.

<table>
<thead>
<tr>
<th>Simple motion</th>
<th>Complex motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motion</td>
<td>Pattern 1</td>
</tr>
<tr>
<td>Motor</td>
<td>Pattern 2</td>
</tr>
<tr>
<td>Imagination</td>
<td>Pattern 3</td>
</tr>
<tr>
<td>Pattern 4</td>
<td>Pattern 4</td>
</tr>
</tbody>
</table>

In this experiment, 4 sessions are carried out in 1 day. According to the time chart as shown in Fig. 3, we have the subject perform the actions of four patterns in 1 session, in which 4 trials of measurements are carried out. Hence a total of 16 trials are carried out in 1 day.

The subject performs one of actions of four patterns at arbitrary timing in every about 10 sec during 1 trial. The EEG data in the trigger action that is performed without "Motion" and "Motor Imagination" is referred as Pattern 5.

After the first experiment, we have the subject perform a training of the motor imagery for one week. After that, the next experiment is carried out again on another day. The training which consists of "Simple Motor Imagination (Pattern 2)" and "Complex Motor Imagination (Pattern 4)" is carried out according to the time chart every day. Any feedbacks are not given to the subject during the training.

In order to extract EEG data to analyze, we have the subject raise his left leg as trigger action just before action of each pattern for a moment. The time when EMG signal measured from the left leg exceeds a threshold is set as a trigger, so that we can obtain the EEG signal of 4 sec period, from 3 sec before the trigger to 1 sec after the trigger.

Except for several EEG data mixing some artifacts, we obtain the averaged signal for each behavior pattern by adding the remaining data. By applying the MWT and DI analyses to the averaged signals, we investigate spatial and temporal features on BP for each behavior pattern.

4. Results

4.1 The results of the EEG signal and MWT

In order to reduce the influence of the trigger action, first, we have calculated the difference between EEG for each behavior pattern and EEG in the trigger action (Pattern 5). Next, we have obtained the averaged signal for each behavior by adding the calculated difference signals.

Fig. 4 - Fig. 7 show the results of applying the MWT to the averaged signal at the Cz electrode in -2 sec ~ -0.5 sec period when BP may appear.

Fig. 4. EEG for each behavior before training.  
Horizontal axis : -2 ~ -0.5 [sec]  
Vertical axis : 20 ~ -20 [μV]

Fig. 5. EEG for each behavior after training.  
Horizontal axis : -2 ~ -0.5 [sec]  
Vertical axis : 20 ~ -20 [μV]
Let us compare the waveforms before training with the waveforms after training using Fig. 4 and Fig. 5. It can be seen the waveforms after training have characteristic "mountains" which are indicated as green rectangles. The "mountain" of the waveform after training has smaller range and larger slope than before training.

That leads us to consider the character of the waveform may appear in frequency region, so that we have applied the MWT to the averaged signals. Fig. 6 and Fig. 7 show the results of applying the MWT into the EEG of each behavior before and after training.

From the result of the MWT for EEG before training as shown in Fig. 6, we can see the phenomenon that the power of frequency intermittently becomes strong (such as arrows) several times in the low-frequency region of 1Hz to 3 Hz. On the other hand, as for EEG after training, the power of frequency in the period of -1 to -0.5 sec only once becomes strong in the low-frequency region which is indicated as the red rectangle. That has suggested that a certain difference exists in behavior of BP before training and after training.

However, from the results of this experiment, the relative difference between “Motion” and “Motor Imagination” or between “Simple-motion” and “Complex-motion” has not been confirmed.

4.2 The results of the DI analysis

In the same way as the MWT, after calculating the difference between EEG signal for each behavior pattern and EEG signal in the trigger action, we have obtained the averaged signal for each behavior by adding the calculated difference signals.

We have applied the DI analysis to the averaged signals obtained at C3, C4, Cz, Fpz and Oz electrodes. In this analysis, we have employed the averaged signal in -2 sec ~ -0.5 sec period when BP may appear.

As an example of these results, we show the flow of information for Pattern 1 as shown in Fig. 8. The blue and red lines indicate the inflow amount of information into C3 and the outflow amount of information from C3, respectively.

In addition, Fig. 9 and Fig. 10 show the inflow amount and the outflow amount of information for Pattern 1 ~ 5 at each electrode, where “Class” used in the figures means “Pattern”. These curves mean the averaged flow amount of information, and have been obtained by adding the amount of information.
Fig. 9. Averaged inflow amount of information into Fpz, C3, C4, Cz and Oz. 
Horizontal axis : -2 ~ -0.5 [sec]  Vertical axis : 3.5 ~ 4.8 [bit]

Fig. 10. Averaged outflow amount of information from Fpz, C3, C4, Cz and Oz. 
Horizontal axis : -2 ~ -0.5 [sec]  Vertical axis : 3.5 ~ 4.8 [bit]
It can be seen from Fig. 9 that the averaged inflow of information becomes the minimum at about 0 sec. The similar phenomenon for each behavior pattern has been also observed in each electrode.

Furthermore, we can see from Fig. 10 that the averaged outflows of information from C3, C4 and Cz electrodes also become the minimum at about 0 sec. However, it has been seen that the fluctuation at Fpz is smaller than at C3, C4 and Cz electrodes, and it in Oz is hardly changed.

Now, we have so far confirmed the averaged outflow and inflow in each electrode in Fig. 9 and Fig. 10. Next let us investigate the outflow and the inflow of information among the electrodes.

The prefrontal area of the brain corresponding to the location of Fpz is indicated to have two functions. One is the function to manage the cognition and the execution such as the reasoning and the switch of actions. The other is the function to manage the higher emotion and motivation, in which it leads to decision-making process.

Moreover, the BP begins about 2 to 1 sec before the voluntary movement onset, and it appears to the left and right symmetry around Cz. The BP is the slow negative EEG activity that appears only by voluntary movement, so there will be some kind of decision-making just before the voluntary movement different from the reflex action.

Therefore, we suppose that some information about decision-making flow toward Cz from Fpz, and then investigate the amount of information that flows each other between Fpz and Cz. Fig. 11 shows the averaged amount of information flowing toward Cz from Fpz in each behavior pattern. Conversely, Fig. 12 shows the averaged amount of information flowing toward Fpz from Cz in each behavior pattern.

From these results, we can see the averaged outflow amount of information at Cz varies larger than the one at Fp in 1 sec to 2 sec before each movement onset.

Furthermore, in order to clarify the flow direction of information between Fpz and Cz, we have taken the difference between the amount of information which flows from Fpz to Cz and the one which flows from Cz to Fpz.

Fig.13 shows the flow direction of information between Fpz and Cz. The positive value shows the amount of information flowing to Cz from Fpz, while the negative value shows the amount of information flowing to Fpz from Cz.

From the result as shown in Fig. 13, it is confirmed that the information is mainly flowing to Fpz from Cz in 1 sec to 0 sec before each movement onset. However, except for the period, it is mainly flowing to Cz from Fpz.

In addition, when we have checked through all subjects, the result that the inflow and outflow of information between Fpz and Cz were reversed at intervals of 0.5 sec to 1 sec has been also obtained.
5. Discussion

From the results of the time-frequency analysis using the MWT, as for EEG before training, we have seen the phenomenon that the power of frequency intermittently becomes strong several times in the low-frequency region of 1 Hz to 3 Hz. However, as for EEG after training, we have seen the phenomenon that the power of frequency in the period of -1 to -0.5 sec only once becomes strong in the low-frequency region. These reactions may be considered to have arisen because the components of the low frequency region, such as BP related to voluntary movements, were unified to the one or unnecessary components were deleted.

From the results using the directed information analysis, we have seen that the averaged outflow amount of information from Cz begins to increase from about -1.5 sec, and arrives at the peak at about -0.5 sec. And then it decreases and becomes the minimum at the voluntary movement onset. These results suggest that some information about the voluntary movement has occurred from 1.5 sec before the voluntary movement onset, and then the occurrence of information has been completed by the time when the behavior movement begins.

6. Conclusion

In this paper, we have investigated differences among behaviors of BP which is one of the components of MRCPs, during the motor imagery of simple movements and complex movements of fingers.

From the MWT results, we have confirmed that the components of the low frequency region, such as BP related to voluntary movements, are unified to the one or unnecessary components are deleted. That has suggested that a certain difference exists in behavior of BP before training and after training. However, clear differences among the behavior patterns can not be confirmed.

From the results of DI analysis, we have confirmed that the information is mainly flowing to Fpz from Cz in about 1 sec to 0 sec before each movement onset, whereas it is mainly flowing to Cz from Fpz except for the period.

In addition, we have confirmed through all subjects that the inflow and outflow of information between Fpz and Cz are reversed at intervals of 0.5 sec to 1 sec.

In the future, by analyzing components such as negative slope (NS') and motor potential (MP) as well as BP, we will find some features to discriminate each behavior pattern.

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References


