The Detection of the Rise to Stand Movements Using Bereitschaftspotential from Scalp Electroencephalography (EEG)

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Abstract: The negative-going Bereitschaftspotential (BP) is associated with the preparation and execution of dynamic movement. So far, BP for simple movements involving either the upper or the lower body has been studied. However, BP has not yet been recorded during both movements. Our study reveals that the negative-going BP was evoked around 3 to 2 seconds before the onset of the rise in response to a start cue. The BP had a negative peak before the onset of the movement of the trunk. BP for the rise to standing up was started around -3 seconds. The corresponding BP while seated could not be recorded in response to the other start cue. Then we tried to discriminate the onset for rise to stand, and for keeping seated using BP data in time domain. BP for 0.5 seconds in the time window is used for the time-shifted leave-one-out cross validation method. The method shows that using 0.5 seconds to 2 seconds before the onset of the movement could detect whether the subject would stand up or keep seated with the correction rate of about 60% to 70%. These results suggest that using the negative BP can detect the subject’s will to stand-up.

Key Words: Bereitschaftspotential, latency, rise to stand, time-shifted cross validation method, linear discrimination analysis.

1. Introduction

Movement-related cortical potentials (MRCPs) in electroencephalograms (EEGs) have been evaluated during the periods preceding the voluntary movement [1]–[3]. Bereitschaftspotential (BP) or the “readiness potential” is a negative-going potential starting 1 second to 2 seconds before the movement onset [4]. BP is maximal at the midline centro-parietal area, symmetric and widely distributed over the scalp [5]–[8]. Previous studies have shown that the supplementary motor area (SMA) is involved in the generation of it. It is certain that BP is related to the preparation and/or execution of voluntary movement. It allows the evaluation of the cortical efferent process and other higher processes controlling voluntary movement [1],[9],[10]. BP is observed during several body movements [9],[10]. So far, BP has been recorded during mouth opening, finger, hand, and foot movements [1],[2],[5]–[17]. Previous studies have not yet described the BP for rise of stand-up movements. The standing movement is a dynamic movement [18]. Four phases are involved in the rise. In the first phase, the flexion momentum is used to generate the initial momentum. The second phase begins as the individual leaves the stool seat and ends at the maximal dorsiflexion. In the third phase, the body rises to its full upright position. In the last, the whole body is stabilized. These phases are differentiated in terms of momentum and stability characteristics.

We therefore focused on the rise to stand behavior and measured BP during the movement. It is necessary to establish the BP dynamics of functional activities, such as rising to a standing position in healthy individuals in order to supports the patients who have neurological impairments in difficulties in sit-to-stand [18]–[20]. The latency between the BP onset and the onset of the surface electromyogram (EMG) are seen in individuals with impairments [21]. Some apparatuses help the individuals to support the sit-to-stand behavior [19],[20],[22]. To use the apparatuses, the timing for the onset of the rise to stand is important to support the behavior. Usually for the timing of the support tool, the onset of EMG is used [21]. But the interval between the onset of EMG and the onset of the movement is so short. As described previously, BP starts 1 second to 2 seconds before the onset of the movement. So, instead of EMG, if EEG is used in the support tool for sit-to stand, it takes a long time to control the timing for the sit-to-stand behavior.

The decoding of the preparatory activity of BP for voluntary movement may be helpful in various regards. Bulea et al. [23] found that using delta-band EEG in frequency domain, the researchers can discriminate the movement type of the standing. But the study did not make clear when they can discriminate it before the onset of the movement.

We recorded EEGs from healthy participants while they were standing up from a stool. The experimental paradigm was conventional and designed to record the scalp surface EEG during the preparation and execution of the rise to stand movement. We also recorded the gyro sensor signal located at the participants' back. The preliminary work of the present study was presented in the SICE2016 conference paper [24]. The conference paper demonstrated the BP and the correlation between the BP peak and the movement parameters that we found for rise to stand-up. In this article, we could discriminate between BP related to the rise of stand-up and BP related to seated before the onset of the movement.
2. Materials & Methods

2.1 Participants

The study included 6 healthy volunteers with no motor impairments in the experiment (6 males; age, 26.8 ± 3 (mean ± standard deviation [SD]) years) who provided written informed consent; the study was approved by the ethical committee of Kyushu Institute of Technology. The volunteers were highly motivated to perform the task. The objective of the study and the procedure of the experiment were explained to all the participants just before the experiment.

2.2 Experimental Procedure

The participants were requested to relax and to sit on an armless, backless stool, which was adjusted according to each participant’s knee height. They were then instructed to rise without moving their hands. The backs of the trunk of the participants move forward at first. Their buttocks then leave the stool. Finally, the bodies were risen to their full upright positions and the whole body was stabilized. The participants were also requested to open their eyes and to gaze toward the front during the rising movement.

The experimental timing diagram was shown in Fig. 1. Each trial lasted for 33 seconds and started with a visual fixation cue shown on the computer screen in front of the participants around 150 cm from their faces and it remained for 33 seconds on the computer screen. There were two types of the visual fixation cues, “+” and “X”. The “+” indicated that the participants were to stand up and the “X” indicated that they were to be seated. Three seconds after the visual cue, an auditory cue beep was presented to the participants for 1 second. After offset of the beep, the participants were required to either stand up or to be seated. When the participants had to stand up, they had to wait more than 1 second after the end of beep, and then they stood up. After standing up, the participants were seated until 30 seconds after the beep. Then, a new visual cue appeared, and a new trial began. The participants practiced before the actual recording started. Each participant performed a session of 50 trials. In each session, 30 trials for rising and 20 trials for being seated were administered randomly. The visual and auditory cues were presented by the Matlab (Mathworks Co., USA) program.

2.3 EEG Recordings

EEG was recorded from 6 Ag/AgCl electrodes placed at F3, Fz, F4, C3, Cz, and C4 according to the international 10/20 system. All electrodes were referenced to mastoid electrodes, and the common ground signal was obtained at Fpz. EEG signals were filtered using a bandpass of 0.05 Hz to 30 Hz and amplified in magnitude by an order of 1,000 (BIOamplifier, DIGITEX Lab. Co. Ltd., Japan). Electrode impedance did not exceed 5 kΩ. Electrooculograms (EOGs) were recorded using electrodes placed at the sides and the lower canthi of the left eye. They were simultaneously recorded to remove blink and eye movement artifacts from the EEG. A gyro sensor was placed near the latissimus dorsi to record the onset of the rise to stand movement. The signal was amplified by a magnitude of 380 and was DC-filtered (INTERCROSS-410 amplifier, Inter- cross Co. Ltd., Japan). All of the EEG, EOG, and gyro sensor signals were converged onto a PC through an A/D converter unit (AIO-16320FX-USB; CONTEC Co., Ltd., Japan) using the signal recording software LabDAQ (Matsuyama Advance Ltd., Japan). The signals were sampled at 1,000 Hz.

3. Data Analysis

3.1 Raw Data

EOG artifacts were identified by visual inspection and the trials with the artifacts were excluded. After the exclusions, 18 ± 5 trials remained (mean ± [SD]) per participant. In the analysis, EEGs were high-cut filtered at 4 Hz using EEGLAB [25]. The onset of the gyro signal change (Gyro onset) was defined as time zero in the EEG figures. The time-frame of the data ranged from -4 seconds to 3 seconds based on Gyro onset. EEGs obtained between -4 seconds and -3 seconds were used for baseline correction.

The Gyro onset was determined based on the local estimation of noise spectra [26],[27]. In this method, mean and variance are computed from the energy of Gyro signal. The condition which the Gyro onset must satisfy is given as:

\[ |G_e(t + T) - N(t + 1)| > k \sigma, \] 0 seconds \( \leq t < 0.2 \) seconds

where \( G_e(t) \) is the energy, \( N(t - 1) \) is estimated of initial energy of 0.2 seconds signal. \( k \) is a tunable threshold parameter. Its value is 1. \( \sigma \) is the variance of the Gyro signal \( G_e(t) \) in the time window. \( T \) increased by 0.2 seconds.

The BP started between -3 seconds and -2 seconds and for detection of the BP start, the EEG was divided by 0.1 seconds. Using EEG in the time window of 0.1 seconds a slope was calculated using a least squares approximation. The early BP had a small negative going slope. The early BP start time was determined by -0.01 < the slope < -0.005.

3.2 Statistics

One way analysis of variance (ANOVA) was used for the statistical analysis of the rise at each EEG channel (F3, Fz, F4, C3, Cz and C4) during the BP.

A post-hoc test (Scheffe’s test) was used to assess the significant differences between the averaged potentials prior to onset (PO), “during” onset (O) and onset onward (OO), over consecutive time intervals from -4 seconds to -2 seconds, -2 seconds to 0 seconds, and 0 seconds to 2 seconds, respectively. The comparisons were performed among all of the participants. For all statistical tests, the level of significant probability was set at \( p < 0.05 \).

3.3 Time Shifted Leave-One-Out Cross Validation Method

There are 30 trials for rising to stand up and 20 trials for being
Fig. 2 The averaged EEG extracted during standing up for a participant. The vertical broken line indicates time 0. Time 0 indicates the gyro onset.

Table 1 number of successful trials in each participants.

| Trials | No. of Participants | Standing | Seated |
|--------|---------------------|----------|--------|
| Sub A  | 26                  | 16       |        |
| Sub B  | 26                  | 14       |        |
| Sub C  | 12                  | 7        |        |
| Sub D  | 8                   | 9        |        |
| Sub E  | 11                  | 6        |        |
| Sub F  | 30                  | 20       |        |

At first raw EEG potential dimension was reduced at 92 from 1000 samples per second. The potential from -4 seconds to 0 seconds was used to discriminate the rise-to-stand-up from the being seated potential using support vector machine classifier (SVM). We used one linear kernel function to check how the classifier discriminate them, the leave-one-out cross validation method was used and the discrimination accuracy rate was calculated. The reduced dimension samples for 0.5 seconds was given to SVM classifier as the input. Then the time window was shifted by 0.5 seconds to the Gyro onset to get the time course of the rate.

4. Results

The results of the averaged EEG in one participant are shown in Fig. 2 based on the Gyro onset. The Gyro onset reflects the onset of the trunk movement. Averaged value of BP start time were 2.95 seconds ± 0.54 seconds before the onset of the movement. The BP start time were as given 3.4 seconds ± 0.24 seconds, 3.08 seconds ± 0.54 seconds, 2.89 seconds ± 0.19 seconds, 2.2 seconds ± 0.32 seconds, 2.5 seconds ± 0.54 seconds, and 2.9 seconds ± 0.40 seconds in Sub A, Sub B, Sub C, Sub D, Sub E, and Sub F, respectively. In Fig. 2, around 3 seconds before the Gyro onset, the potential gradually decreased and reached the maximum negative peak around 0.1 seconds - 0.3 seconds after the Gyro onset. The potential then increased and reached a positive peak around 0.7 seconds - 0.8 seconds after the Gyro onset. The EOG did not change during this period. Therefore, the change in BP does not reflect a change in the EOG. The
change in the potential at Cz was a little larger than those at the other electrode positions. The start time of BP was similar to those recorded in the previous studies [2],[14],[28]. The averaged value of BP start time were 2.95 seconds ± .54 seconds based on Gyro onset from all the subjects.

Figure 3 shows the statistical data based on the Gyro onset for one participant. We calculated the time average of the EEG potentials during three different periods: BBP, BP, and ABP. Significant differences were found between BBP and BP at the electrode positions Fz, C3, Cz and C4 (p < 0.05 at Fz C3, Cz and C4). Figure 4 shows the average of seated EEGs in one participant. Note that zero indicates the time when the auditory cue appeared. Negative and positive deflections were not observed in the averages. Next, we performed the time shifted leave-one-out cross validation method. Figure 5 shows the averaged accuracy rate for the discrimination between the rise to stand-up and seated potential. The max accuracy rate was obtained at -0.5 seconds, that is, 0.5 seconds before the onset of the movement. It was 0.65 ± 0.10 for the combined both rise to stand-up and seated. Individually, it was 0.80 ± 0.10 for rise to stand-up and 0.40 ± 0.10 for seated. It is significantly larger than the rate at the baseline (significant probability = 0.0004), that is, at -3.5 seconds. In the other three participants, the max rates were 0.67 ± 0.11 at -1.5 seconds, 0.7 ± 0.10 at -2 seconds, and 0.68 ± 0.20 at -2 seconds. They are significant compared with the rate at -3.5 seconds. In the rest of two participants, the significant max rate was not obtained.

5. Discussion

Here we describe the motor-related cortical potential associated with the preparation for rising to stand up. The purpose of this investigation was to observe the BP associated with the rise to stand from a seated position and to know how long we could discriminate the participant’s will to stand up using BP. The cortical potentials associated with the voluntary movements of various body segments are known as MRCPs. The potentials will indicate the preparation and execution of controlled voluntary movement [4],[9]. BP is one of the MRCPs has slow negative-going potential for the preparation for the movement. It starts just 2 seconds before the onset of movement [2]. Previous MRCPs studies have been based on mouth, finger, hand, and foot movements [1],[2],[5]–[17]. We thus studied the rise to stand behavior. Here, BP was started between 3 seconds to 2 seconds before the onset of the movement (Fig. 2). The BP was significantly negative compared with the averaged potential prior to onset (Fig. 3). Figure 4 shows the EEG while the subject was seated. The negative potential was not observed during the period. Thus, the negative component in Fig. 2 may be the BP for the rise to stand movement.

BP is generated in several cortical and subcortical structures that are linked with the motor area [5]. It is widely distributed on the scalp above the vertex, and central, prefrontal and parietal areas [2],[12],[14],[15]. Among them BP recorded at the vertex has the maximal amplitude [5],[6],[8]. In the present study, BP had the larger negative peak at Cz (Fig. 2).
negative-going BP preceding the rise to stand in the present study is similar to the waveform seen during voluntary movements in previous reports [1],[2],[6],[8]–[15]. We found that BP for the rise to stand movement could be induced before the onset of the movement. Then, we checked whether using the BP, we will predict the participant’s will of standing-up and being-seated. One of the co-author and other researchers have developed support tool for the elderly or those with disabilities [19],[20],[22],[29]. It will be difficult to find the timing to support the users. To find the timing the previous researchers have used EMG. The interval between the onset of EMG and the movement is too short. So it was too short to detect EMG and to control the tool. Hence, we have proposed EEG instead of EMG. It may take some time to detect and process the BP and to control the support tools. BP can be induced about 2 seconds before the onset of the rise. Actually using BP we could discriminate BP related to the rise from one to be seated, and we may predict the participants’ will to stand up. Using the BP, we could then control the support tool for the person using the device to stand up. In a previous study, it was argued that elderly persons may require different strategies for standing up than younger ones [30]. Thus, in the future, we will study whether we can record BPs from the elderly persons such as in the present study.
In conclusion, the BP started 2 seconds before the onset of the rise to stand-up movement. From BP we could discriminate the rise to stand-up and seated movement. It could be used for support tool to stand-up movement.

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