Effect of neurofeedback training on event-related desynchronization strength by motor imagery

Kenya WADA[1], Hidenori KAYANUMA[2], Miku MATSUBARA[2], Naoto SEKI[2], Masaya KURATA[1], Daiki TAKEHARA[1], Yumie ONO[1]

[1]Department of Electronics and Bioinformatics, School of Science and Technology, Meiji University

[2]Electrical Engineering Program, Graduate School of Science and Technology, Meiji University

Abstract: We investigated the transition of event-related desynchronization (ERD) intensity through 6 days of brain-machine interface (BMI) training using Digital Mirror Box (DMB), which is a potential rehabilitation system for stroke patients with hand paralysis. Eleven healthy participants performed motor-imagery of grasping their dominant hand under the observation of hand movement video. The overall ERD strength of all participants showed a significant increase from day 1 to day 6. When the participants were divided into high and low ERD groups by their initial ERD strength of higher or lower than 0% at the initial measurement before BMI training, respectively, participants in low ERD group showed larger training effect. These results suggest that BMI training is particularly useful for increasing the ERD strength of stroke patients who have lower ERD strength.

Keywords: BMI, event-related desynchronization, neurofeedback training

1. Introduction

Stroke is a disease of obstruction within or ruptures of a blood vessel in the brain that causes movement disorders such as hemiplegia. Patients with stroke usually undergo rehabilitation to restore the impaired motor function. Rehabilitation of hand paralysis is particularly important since the hand function has a great influence on life. Brain machine interface (BMI) is a promising technique to help reconstruct the damaged motor pathway and to restore the motion of the hemiplegic hand by providing sensory feedback according to the intention of the patient's hand movement [1]. Many stroke rehabilitation systems use Event-Related Desynchronization (ERD) to return feedback to the patient for motor imagery [2, 3]. ERD is a suppression of μ band activity (8-13 Hz) found during motor imagery or actual movement in the motor cortical areas corresponding to the body part of intended movement, indicating the active state of the motor cortex. The goal of these BMI rehabilitation techniques is to increase the ERD of the affected hemisphere in the patient to the point where they would convey motor intent directly to their paralyzed hand. However, there are individual differences in the ability of the motor imagery [4]. Therefore, it would be necessary for a stroke patient to assist their ability of motor imagery to perform ERD - based BMI rehabilitation. Therefore, we developed an ERD-BMI rehabilitation device called the digital mirror box (DMB) [5, 6]. This system assists the motor imagery of the participant by providing the hand motion picture displayed on the tablet screen and strongly inducing the ERD response [6]. When the ERD exceeds the threshold, DMB provides somatosensory feedback via exoskeleton robot attached to the affected hand in synchronization with the hand motion video to promote the development of sensory-motor pathway of the patient.

In this study, we examined the transition of motor-imagery (MI) related ERD strength in young adult participants through 6 days of DMB training and investigated the characteristics of the participant who could benefit from the proposed neurofeedback training.

2. Materials and Methods

Eleven healthy young adults (7 male, 4 female, 20.4 ± 0.5 years old) participated in the experiment. The study was approved by the Institutional Review Board and all participants gave written informed consent prior to participation.

We recorded EEG at C3 or C4 of the international 10-10 electrode system using g.USBamp (g.tec medical engineering GmbH, Austria) at the sampling rate of 256 Hz with 0.5-30 Hz band-pass filter. The dominant hand of the participants was tested. BMI training was consisted of a session of evaluation data collection and a session of DMB training (Fig. 1).

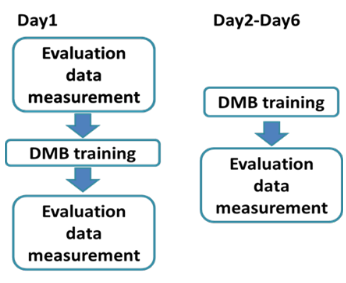

Figure 1. Experimental schedule

A. DMB training system

(a) Training protocol

Participants performed DMB training to increase ERD strength. In the DMB training system participants wore a glove-like, assistive exoskeleton robot (Power Assist Hand: Team ATOM, Atsugi, Japan). It is a pneumatic device used to change the hand shape to either being grasped or open. The participant sat on a chair and placed his/her dominant hand on the table. A tablet screen was placed in front of the hand to be tested. Participants watched a movie on a tablet. A single training trial was consisted of a movie containing 5 Training periods with inter-period interval (White screen) in between (Fig. 2). Each Training period began by displaying a blue fixation cross on a white screen (preparation cue, 4 s) to remind the participant to relax and to pay attention to the side of the screen where a hand action movie would be presented. The fixation cross was followed by a 6 s movie of a moving hand (Analysis period) to encourage the participant to intend the hand motion. The Analysis period was followed by a red fixation cross for 4 s and the same hand movie shown in the Analysis period (Exoskeleton operation period). The sensory feedback via exoskeleton device was given in this Exoskeleton operation period depending on the ERD strength detected in the preceding Analysis period. Participants performed five trials per day. The training was continued for 6 separate days in 2 weeks with 1-3 days of inter-training intervals.

We extracted two sub-periods of EEG data for rest and task (motor imagery) conditions in each Analysis period. The rest period corresponds to the EEG data recorded for 1 s before the ball appears. The task period corresponds to the EEG data recorded for 2 s immediately after the ball appears (Fig. 2), in which participants were encouraged to imagine the hand motion while observing the hand motion pictures. We calculated the power spectrum for 8-13 Hz of these two data sets using the wavelet transform, and defined ERD strength with the following equation (1):

$$\text{ERD strength} = 100 \times \frac{\mu_{rest} - \min \mu_{task}}{\mu_{rest}} \; [\%] \qquad (1)$$

Where μ_{rest} denotes the μ band spectrum power obtained during the rest. The $\min \mu_{task}$ was the minimum μ band spectrum power for any 1 s during the task period. If the ERD power at the rest and task periods satisfied the predetermined threshold, the exoskeleton hand gave somatosensory feedback with the visual feedback being displayed on the tablet screen in Exoskeleton operation period. Users could receive proprioceptive feedback via the exoskeleton hand to confirm whether they could properly imagine the hand action specified.

(b) Difficulty setting

To be able to train the participant with appropriate ERD strength, we set a threshold of ERD value (Threshold) to decide whether the exoskeleton hand would operate.

The first trial of the training day 1 starts from Threshold of 10%. That is, in any user, the exoskeleton hand moves when the ERD strength exceeds 10%. In the second trial of the training day 1, Threshold remains unchanged if the participant could operate the exoskeleton hand no more than twice in the first trial. In case that the participant could operate the exoskeleton hand three or more times, the average of non-negative ERD strengths in the first trial was calculated. The new Threshold was set to the integer multiple of 10% that would not exceed the value 10% lower than the average of non-negative ERD strengths in the first trial. (for example, Threshold was set to 20% if the average of non-negative ERD strengths was 37%). Threshold was adjusted by 10% increment or decrement for every trial afterwards in the same experimental day according to the following rules. (1) Threshold was increased by 10% if the participant could operate exoskeleton hand three times or more in the preceding trial. (2) Threshold was decreased by 10% if the participant failed to operate the exoskeleton hand at any Training period. Otherwise, Threshold was maintained with the same value in the preceding trial. In the first trial of the next training day, Threshold was set to 10% lower than the Threshold at the last trial on the previous training day.

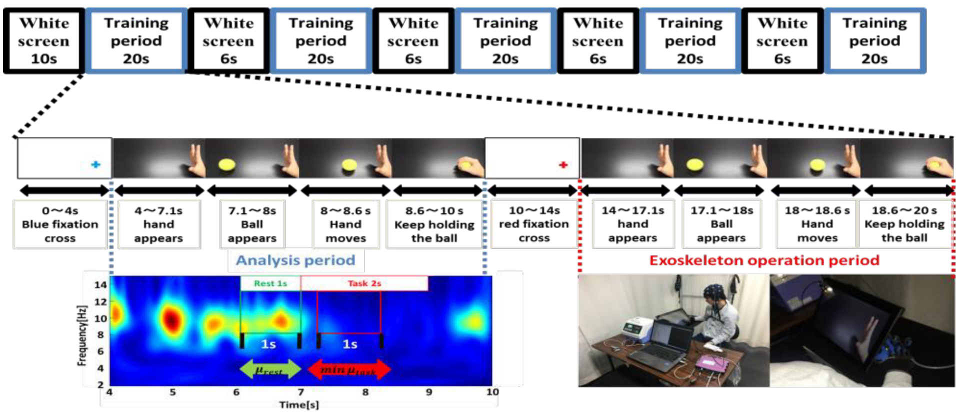

Figure 2. Movie stimulus for a single trial of hand motor-imagery training in DMB

B. Evaluation of MI-related ERD strength

Participants performed ERD measurements under MI to evaluate the effect of training. The participants sat on a chair and relax, placing their dominant hand on a table. A tablet screen was placed in front of the hand to be tested. Each trial (12 s; Fig. 3) started with white screen (relax cue, 4 s). Next, a gray fixation cross was displayed on the white screen (preparation cue, 4 s) to encourage participants to keep relaxed but prepare for MI. When the color of the fixation cross was switched to black (imagery start cue, 4 s), the participants performed MI of grasping the ball once. Once the imagery start cue was presented, participants were asked to stare at the fixation cross and prevent body movement until they finish MI. Participants performed this trial 10 times immediately before the first DMB trial on the first experimental day (day1 pre) and at the end of each day of DMB training (day1 post, day2, … , day6).

C. Data analysis of MI-related ERD strength

We extracted two 1 s-long samples of EEG data for the rest and task periods for each trial in the MI sessions. The rest period corresponds to the EEG data recorded for 1 s before the black fixation cross began. The task period corresponds to the EEG data recorded for 1 s immediately after the black fixation cross (Fig. 3), in which participants were encouraged to imagine the hand grasp motion. We calculated the power spectrum for 8-13 Hz of these two data sets using the wavelet transformation method, and defined MI-ERD strength with the following equation (2):

$$\text{MI-ERD strength} = 100 \times (\mu_{rest} - \mu_{task}) / \mu_{rest} \ [\%] \quad (2)$$

Where μ_{rest} and μ_{task} denote the μ band spectrum powers obtained during the rest and task periods, respectively. Participants with MI-ERD strength of 0% or less at the first screening before DMB training were defined as a low MI-ERD group. The other participants were defined as high MI-ERD group.

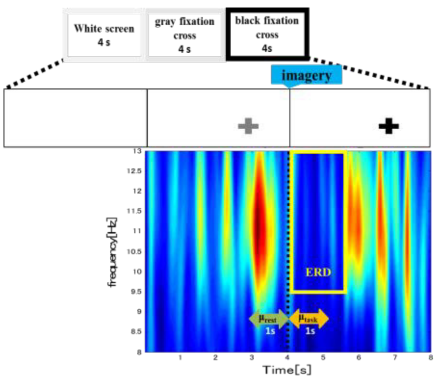

Figure 3. Movie stimulus for MI-related ERD measurement

D. Statistics

Statistically significant difference was examined using t test for the mean MI-ERD strength of all participants between day1 pre and day 6. We further performed a one-way analysis of variance (ANOVA) followed by a Games-Howell post-hoc test on the ERD strength transition from day1 pre to day 6 of the high and low ERD groups. Normality of the data was confirmed by Shapiro-Wilk test. We considered P value < 0.05 to be statistically significant.

3. Result

Figure 4 shows the average MI-ERD strength of the participants at day1 pre and day6. MI-ERD strength significantly increased from day1 pre (-1.46 ± 6.4%) to day6 (21.5 ± 5.4 %, t-test, P = 0.027). Figure 5 shows the transition of MI-ERD strength for each participant. There were individual variations in the values of the MI-ERD strength before DMB training and in the transition of MI-ERD strength during DMB training. Interestingly, the growth rates of MI-ERD showed contrasting results depending on the participant groups. The transition of the average MI-ERD strength in the high MI-ERD group is shown in Fig. 6. The MI-ERD strengths of day1 pre and day6 were 18.8 ± 4.7 and 16.0 ± 9.0 %, respectively, between which we found no statistically significant differences. The transition of the average MI-ERD intensity in the low MI-ERD group is shown in Fig. 7. The MI-ERD intensity was significantly increased from day1 pre (-18.3 ± 3.2 %) to day6 (26.0 ± 6.5 %; Levene's test, p=0.023; Welch's test, P=0.001; Games-Howell test, P=0.005).

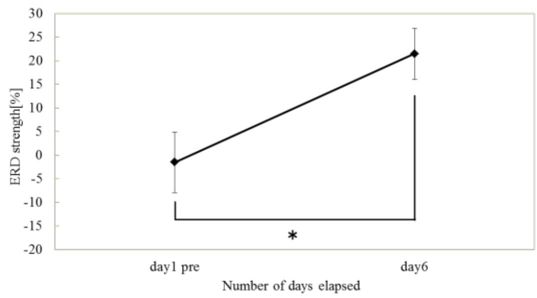

Figure 4. Change in average MI-ERD strength through DMB training

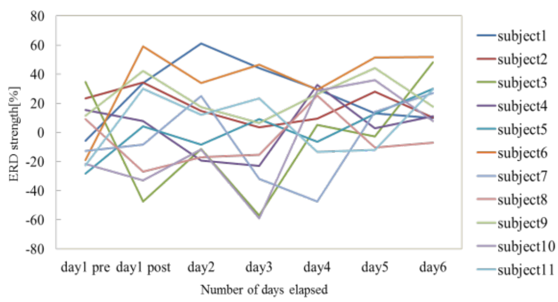

Figure 5. MI-ERD intensity transition for each participant

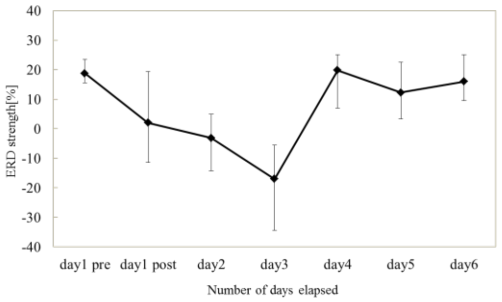

Figure 6. Transition of average MI-ERD strength of High ERD group

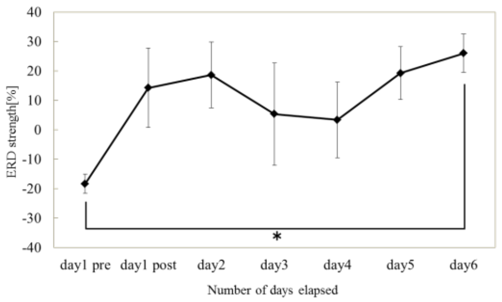

Figure 7. Transition of average MI-ERD strength of Low ERD group

4. Discussion

We examined the transition of MI-related ERD strength in healthy participants who underwent neurofeedback training with DMB-BMI system. Our results showed that the overall MI-related ERD strength increased after the training. We also found that the DMB-BMI system could provide efficient MI-related ERD training especially in participants with lower initial MI-related ERD strength. ERD is considered to be the active state of the motor cortex [7]. Although the restoration of activity in the affected motor cortex is reported to be a good predictor of functional recovery in stroke patients [8], they tend to have lower ERD strength in the affected motor cortex [9]. Our proposed DMB rehabilitation might help stroke patients, who have lowered ERD due to stroke, regain the ERD strength and facilitate the activity of the affected motor cortex for better functional recovery. As a future prospect, we plan to determine the clinical effect of this system. We would also compare our system with the pseudo neurofeedback system that gives random feedback, in order to investigate whether visual and sensory feedback corresponding to the ERD strength could be effective to increase the ERD strength.

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