# Investigation of optimal visual cue for training of motor-imagery response

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**Abstract:** We are developing Digital Mirror Box (DMB), a brain machine interface (BMI)- based rehabilitation system for stroke patients with hand paralysis. Aiming to train the motor-command generation from the affected hemisphere, DMB uses an event related desynchronization (ERD) derived from motor imagery as an operating signal of the BMI feedback. In order to assist the patients to perform motor imagery, the current DMB system presents a movie of hand motion, in which a hand-grasping motion picture is presented immediately after a still image of the fixation point. However, there remains a possibility that the detected ERD is influenced by an attentional switching from still to motion picture, not by action observation or motor imagery per se. We therefore modified the movie to contain a still image of a resting hand between fixation cue and hand motion picture. We could successfully differentiate the μ band suppression of the attentional switching from those derived from motor imagery.

**Keywords:** BMI, ERD, motor imagery

## 1. Introduction

Recent advance in brain measurement techniques enables stroke patients to utilize a brain machine interface (BMI) for rehabilitation of their affected motor functions. We are developing Digital Mirror Box (DMB) [1, 2], a BMI rehabilitation system for stroke patients with hand paralysis. DMB measures EEG from the injured motor cortex and detects event related desynchronization (ERD) derived from motor imagery under hand action observation. When ERD is detected, the patients are given somatosensory and visual feedback by the exoskeleton robot attached to the hand and the tablet screen placed in front of the hand, respectively. In synchronism with this movement of the hand via the exoskeleton robot, the tablet screen gives a visual stimulation in a first-person perspective as if the hand of the patient actually moves. This system aims to promote early recovery of the affected motor cortex by giving visual and sensory feedback that is synchronized with motor imagery.

The central pathway that transmits motor commands from the motor cortex to peripheral motor neve is damaged in stroke patients. The purpose of stroke rehabilitation is to reconstruct this motor pathway. Since the recovery of hand functions of stroke patients is associated with the increasing strength of ERD from the affected hemisphere during motor imagery, ERD is considered as an index related to recovery of the motor cortex [3]. Therefore we use ERD as an operating signal for our DMB system, and provide hand action movie to stimulate the once damaged motor cortex via mirror neuron system to induce robust ERD response. Our current DMB system is now under clinical trial to confirm its feasibility in stroke hand rehabilitation [2, 4].

Although the current DMB system works fine in detecting ERD and controlling the exoskeleton robot, it still has a point to be considered. In order to assist the patients to perform motor imagery, the current DMB system presents a movie of hand motion, in which a hand-grasping motion picture is presented immediately after a still image of the fixation point (Fig. 1). However, oscillatory EEG activity could change by not only motor imagery but also attentional switching [5]. Thus, there remains a possibility that the detected ERD is influenced by an attentional switching from still to motion picture, not by motor imagery per se. It is necessary to appropriately evaluate the ERD derived from the motor imagery. We therefore examined the change of EEG oscillatory activity at the time of switching the screen and investigated optimal visual cue for DMB.

## 2. Methods

Seventeen subjects (9 male, 8 female, mean age ± standard deviation, 20.1 ± 0.4) participated in the experiment.

EEG signals were recorded with g.USBamp (g.tec Medical Engineering GmbH, Austria) EEG amplifier system. Nine electrodes were placed on the scalp of the participants at locations of F3, FC3, T7, C5, C3, C1, Cz, CP3 and P3, which are based on the international 10-20 system. These channels were selected around the motor cortex of the right hand. However we only used EEG data from C3 for the current analysis. We set the sampling rate, band-pass filter, and notch filter to 256 Hz, 0.5 - 30 Hz, and 50 Hz, respectively.

The participant sat in a chair and comfortably placed his/her right forearm on the table. A tablet screen was placed in front of the hand. We measured EEG during two conditions of (1) action observation with motor imagery and (2) action observation without motor imagery. The stimulus movie of our current system (Fig. 1) first displays a fixation cross, followed by a motion picture in which a hand grasping tennis ball rolling into its palm. ERD is calculated as a ratio of μ band suppression (8-13 Hz) from immediately before to after the motion picture starts. In this case, change in μ band activity is supposed to occur by motor imagery, but at the same time the switching of the screen from fixation picture to motion picture might affect the μ band activity. Therefore we modified the movie as shown in Fig. 2. A still picture of the hand was inserted between fixation cross and hand motion picture to avoid the effect of attentional switching from fixation to hand movie on the calculated ERD strength. In order to further investigate the μ band activity with other hand gestures, we added the movie of opening the once grasped hand at the end of the movie. One trial is consisted of motor imagery under observation of two hand actions and eight trials were conducted for each condition of (1) and (2).

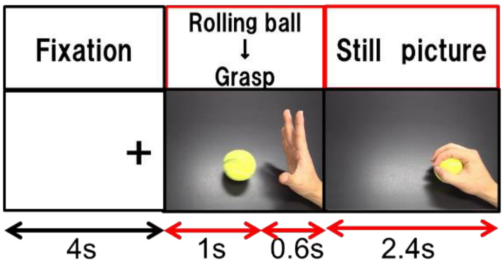

Fig. 1 Movie stimulus for current DMB system

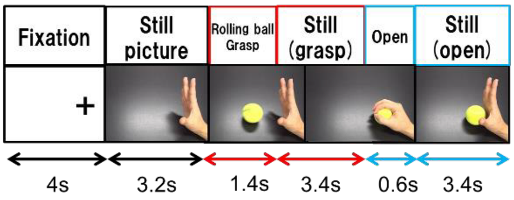

Fig. 2 Modified movie stimulus

We calculated the power spectrum for 8-13 Hz using the wavelet-transform based time-frequency analysis, and defined ERD strength with the following equation (1):

$$\text{ERD strength} = 100 \times (P_{\text{rest}} - P_{\text{task}})/P_{\text{rest}} \qquad (1)$$

We defined $P_{\text{rest}}$ as the mean of the μ band spectrum power obtained during the rest period, which is 1 s before the time points. $P_{\text{task}}$ denotes the minimum mean μ band power for 1 s during 2 s immediately after the above time points. We calculated ERD strengths at the following three time points (Fig. 3).

(a) Switching from fixation point to still picture of a hand
(b) Appearing a ball on the screen
(c) Opening the grasped hand

We examined the influence of attentional switching from still to motion picture in (a). We investigated the change of ERD strength of grasping and opening motor imagery under hand action observation in (b) and (c), respectively.

## 3. Results

Figure 3 shows grand mean μ band activity change across all participants. As seen in this figure, decay of μ band activity was observed when the screen was switched from fixation to still picture of the hand. Figure 4 shows mean ERD strengths in different experimental conditions. The overall mean ERD strength at the time switching from still to motion picture was 26.25%, ERD strengths derived from grasping imagery and opening imagery was 31.70% and 21.51%, respectively. ERD strengths during observation of grasping and opening hand actions without motor imagery were 26.11% and 24.66%, respectively. There was no significant difference between ERD strength at the time point of switching the screen from fixation and ERD strength derived from motor imagery.

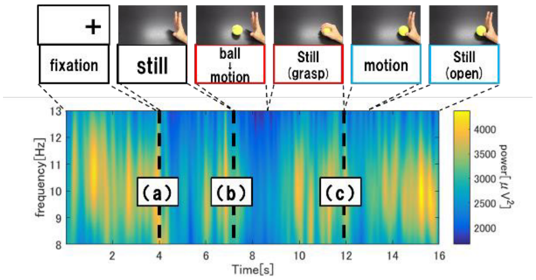

Fig. 3 Analysis time windows and grand mean μ band activity change

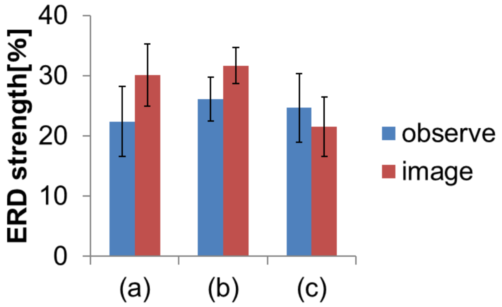

Fig. 4 Mean ERD strength at visual stimuli of (a) switching from fixation to hand image, (b) grasping a hand, and (c) opening the hand under action observations with and without motor imagery

## 4. Discussion

The amount of decrease in μ band activity at the time of switching the fixation to hand image was comparable to that at motor imagery. The attenuated μ band activity returned to the normal state approximately after 3 seconds. Therefore, it was possible to distinguish the motor-imagery related ERD from attenuation of the μ band activity due to visual stimulation.

In the BMI-based motor rehabilitation, it is important to induce ERD from the affected hemisphere. It is therefore necessary to examine the training effect on brain waves. As the ERD strength on the affected hemisphere recovers along with the functional recovery of the paralyzed hand [3], ERD is considered to be a measure of the functional recovery of the motor cortex in post-stroke patients. However, evaluating the ERD strength through motor imagery with the current visual stimuli may be difficult because the ERD strengths were similar between with and without motor imagery. Perry and Bentin [6] previously reported that μ band suppression occurred even while seeing static hand postures. Therefore, a method of evaluating the motor-imagery derived ERD without a picture of the hand is required.

The ERD strength tended to be lower in motor imagery of hand opening compared to grasping. There may be an individual difference in the timing of motor imagery in case of hand opening, or participants might not able to perform robust motor imagery. In case of grasping, the rolling ball appears from the other side of the screen at the right timing for motor imagery, whereas the hand moves suddenly in case of opening the hand. It might be difficult to know the right timing for opening the hand. If the movie stimulus of the hand opening is required for a specific purpose, we need to consider the method of presenting an appropriate timing for imagery.

Our future prospects are to investigate the appropriate evaluation method for spontaneous ERD derived from motor imagery per se and whether ERD strength increases by repetitive training of DMB. In addition, we would conduct DMB training on stroke patients and investigate whether the trained ERD strength correlates with the recovery of motor function.

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