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Treatment effectiveness of brain-computer interface training for patients with focal hand dystonia: a double-case study

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Abstract— **Neuronal mechanism underlying dystonia is poorly understood. Dystonia can be treated with botulinum toxin injections or deep brain stimulation but these methods are not available for every patient therefore we need to consider other methods Our study aimed to develop a novel rehabilitation training using brain-computer interface system that decreases neural overexcitation in the sensorimotor cortex by bypassing brain and external world without the normal neuromuscular pathway. To achieve this purpose, we recorded electroencephalograms (10 channels) and forearm electromyograms (3 channels) from 2 patients with the diagnosis of writer's cramp and healthy control participants as a preliminary experiment. The patients were trained to control amplitude of their electroencephalographic signal using feedback from the brain-computer interface for 1 hour a day and then continued the training twice a month. After the 5-month training, a patient clearly showed reduction of dystonic movement during writing.**

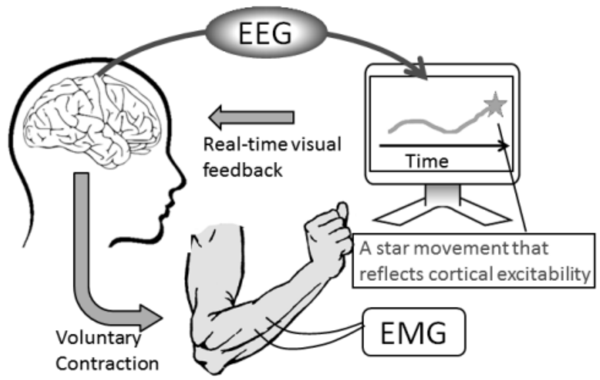

Figure 1. Schematic diagram of the brain-computer interface that feeds back information of cortical excitability in the sensorimotor cortex.

I. Introduction

Dystonia is a disorder of movement characterized by involuntary, sustained muscle contractions, frequently causing twisting and repetitive movements or abnormal postures. Writer's cramp is an example of task specific focal hand dystonia. Writer's cramp has been believed to be due to dysfunction of the basal ganglia rather than a psychological disturbance [1, 2]. A disinhibition and overexcitation of the cortico-basal ganglia-thalamic loop may leads to co-contractions and dystonic postures [3].

Recent transcranial magnetic stimulation study revealed that there is shift in the balance between excitation and inhibition in local circuits of the primary motor cortex in focal dystonia [2]. Sensory evoked potential (SEP) recordings in focal dystonia (and in other types of dystonic disorders) also indicated that in dystonia there is an impaired inhibition at spinal and cortical levels of the somatosensory system which would lead to an abnormal sensory assistance to the ongoing motor programs resulting in the motor abnormalities [4].

Among the different types of dystonia, only writer's cramp, in which symptoms occur only during the process of writing, has been investigated using event-related desynchronization (ERD) traces [5]. In their results, a significantly lower amount of ERD in the 20 30-Hz band was found in dystonic patients compared to controls over the contralateral and midline centroparietal region, from -100 ms to+200 ms with respect to EMG onset. However ERD analysis in whole frequency band such as time-frequency maps has not been used for EEG recorded from a writer's cramp patient. Therefore, one of aims in this study is that to investigate ERD or event-related synchronization (ERS) in broad frequency band to characterize dystonia-related features in EEG.

Recently, Sohn and colleges demonstrated a method to suppress corticospinal excitability using "negative motor imagery". In their study, seven healthy participants were trained to decrease amplitude of magnetic evoked potential with motor imagination [6]. While their method is seemed to be applied for patients with focal hand dystonia to suppress cortical overexcitation, there are some risks for using transcranial magnetic stimulation including fainting, headache, local discomfort or rare occurrence of induced seizures.

This study therefore aimed to develop a motor training system that feeds back information of cortical excitability in the sensorimotor cortex to the user without magnetic stimulation (Fig. 1), and to apply the system for patients with focal hand dystonia.

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II. Materials and Methods

A. Participants

Two patients with the diagnosis of writer's cramp (Patients A, age 60 and Patient B, age 40 years) and two healthy young subjects (age 22 years both) participated in this study. All

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participants were right-handed and gave informed consent for this study, which had been approved by the local ethical committee and the study was conducted in accordance with the declaration of Helsinki. The patients participated in the experiment twice a month over a 5-month period. We conducted a total of 10 days of BCI training. In addition, to evaluate the cortical activity changes caused by the training, we conducted electroencephalogram (EEG) recordings on both pre- and post-training days. Every experiment was finished within 2 hours to avoid fatigue.

B. Motor Task and BCI Training

Each recording day, a participant was requested to perform the following: (1) tonic contraction of the right ECR muscle (tonic motor task) for 60 s; (2) right hand extension with rhythmic auditory cue for 40 times, one every 2.5 s (repetitive motor task) for 40 times; and (3) write Japanese characters with a pen (writing task). During tonic motor task, a participant kept constant extension force with integrated EMG recorded from the right extensor carpi radialis (ECR) muscle. Integrated EMG was computed rectifying and smoothing with a moving average with a window of 1 s.

Patients A and B were additionally conducted EEG feedback training using BCI for 1 hour a day and then continued the training twice a month for 5 months, totally 10 days. The 3 motor tasks describe above were also done twice before and after BCI training.

C. Measurement

We recorded 10-channel monopolar EEG and 3-channel surface EMG from forearm during motor tasks and BCI training with Ag/AgCl electrodes (diameter 9 mm). To record scalp EEG, 10 electrodes were placed at C3 and C4, as designated according to the International 10/20 system, and 2.5 cm anterior, posterior, left, and right to C3 and C4 that were close to the hand representation area. All EEG channels were referenced to the right ear lobe. The ground electrode was positioned on the participant's forehead. The surface EMG was recorded from the right ECR muscle and its antagonist muscles, the flexor carpi radialis (FCR) and flexor digitorum superficialis (FDS) muscles.

All biosignals were band-pass filtered between 2 and 1000 Hz, and simultaneously digitized at 2400 Hz using a biosignal amplifier (g.USBamp, gtec, Austria). The digitized EEG and EMG data were stored on a personal computer for offline analysis.

D. Time-Frequency Representation

In the EEG analysis, we drew ERD/ERS maps using the intertrial variance method [7, 8]. The EEG data were analyzed between 5 and 50 Hz in intervals of 2 Hz. Trials were filtered with a 4th order Butterworth filter, and the ensemble average was subtracted from individual trials (total 40 trials). This operation reduces the contribution of phase-locked responses to the ERD/ERS quantification. The trials were squared and averaged. A moving average window of 250 ms smoothed the ERD/ERS estimation. Reference interval for the relative power changes was between -1.5 and -0.5 s from the onset of right ECR EMG. We used the ERD/ERS maps and to define a participant-specific frequency band responsive to hand movements.

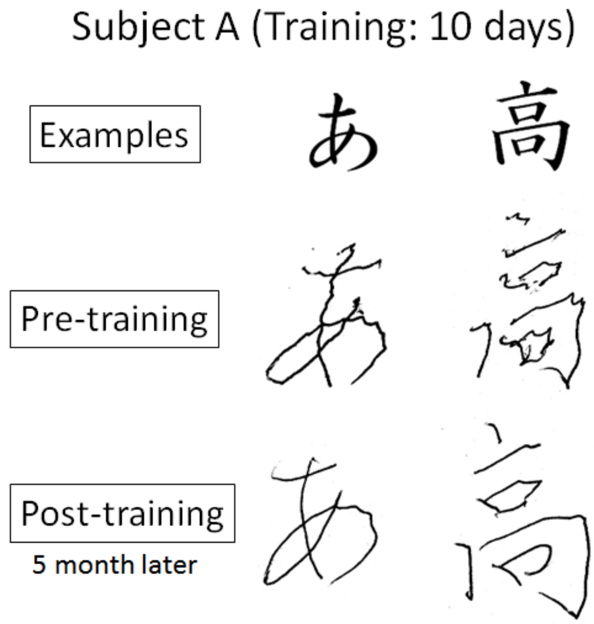

Figure 2. A Example of Japanese characters and handwriting of Patient A (Pre-training and Post-training)

E. Cortico-Muscular Coherence

To access involvement of cortical neurons in motor unit synchronization, cortico-muscular coherence analysis was conducted. The computing process was same as our previous study [9]. Following segmentation of the data stream into70 segments of 1-s duration, the segment was windowed with a 1-s Hamming window, and the Fourier transform was used. The segment length of 1 s leads 1-Hz frequency resolution was.

Coherence was considered to be significant if the value exceeded the 95 % confidence limit, which can be calculated in the same manner as [10] and the value designed to the confidence limits of 0.043 in our experiment.

All analyses were carried out using MATLAB software (The MathWorks, US) with custom-developed programs.

III. RESULT

With 10 times training, Participant A clearly showed reduction of dystonic movement during writing and handwriting of Japanese characters displayed reduction distortion (Fig.2). The patient also gave us the impression that hand rigidity was reduced sometimes during writing in our questionnaire.

In analysis of ERD/ERS, large 28-32 Hz ERS was observed in the pre-training condition. The ERS was disappeared and ERD was appeared in the frequency band of mu or beta rhythms (10-25 Hz) after BCI training. The ERD/ERS maps were shown in Fig. 3. In BCI training condition, we selected this 28-32 Hz frequency band as focal hand dystonia-specific EEG frequency band. Our BCI system mainly fed back the amplitude of the frequency band as an EEG feature value.

The ERS in 28-32 Hz was appeared prior to EMG onset. Four-second EEG and EMG signals in an arbitrarily chosen segment are displayed in Fig. 4.

For comparison, the cortico-muscular coherence spectra obtained from a patient with focal hand dystonia (Patient A) and a healthy participant are shown in the upper and lower row of Fig. 5. Patient A showed peaks in the coherence spectra computed with EEG from left and right each hemisphere in around 30 Hz. The frequency band of this coherence peaks was equivalent to that of large ERS following motor tasks.

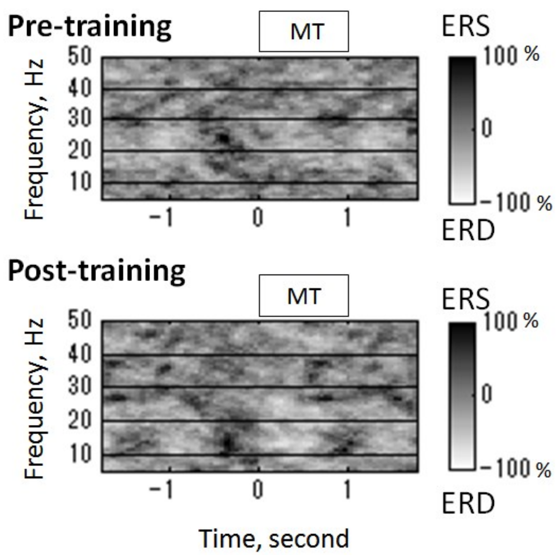

Figure 3. ERD and ERS following the motor task (MT) computed from C3. (The upper row represents the pre-training condition and lower one represents the post-training condition.)

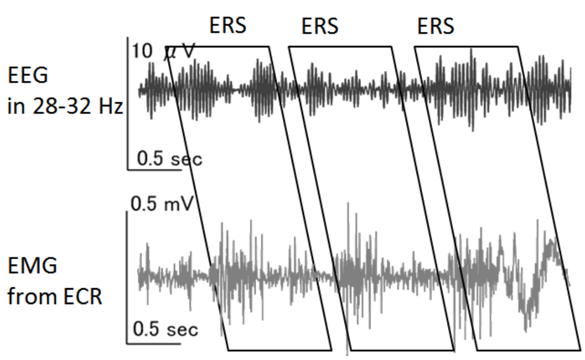

Figure 4. Four-second EEG and EMG examples from Patient A (The EEG was filtered in the frequency range 28-32 to emphasize ERS in the frequency band. The EEG and EMG was recored sinultanously.)

IV. DISCUSSION

We found the large 28-32 Hz ERS in the pre-training condition using the data from patients with focal hand dystonia (Fig. 3). No previous study on ERS/ERD by motor tasks has been reported such large reaction of EEG in the frequency band yet. Therefore we speculate that the EEG power of the frequency band is the dystonia-related features in EEG. In addition, ERS in this frequency band was recorded from both hemispheres. It suggested existence of different mechanism of cortico-muscular coupling from the mechanism in healthy subjects, because the coupling is generally observed between contralateral motor area and contracting muscle in the beta frequency band (18-30 Hz) [10].

In previous studies with healthy participants and patients with other types of dystonia, synchronous activity in EEG has been reported [11-13]. They however reported mostly about beta band activity from contralateral hemisphere. Considering their results, we suggest that there was a neuronal oscillation circuit bilaterally affecting activity in the motor cortex. At least, our data indicated that underlying mechanism of focal hand dystonia should be different from other type of dystonia.

In the result of a patient with focal hand dystonia (Patient A), handwriting was clearly improved and ERD/ERS was changed. Considering the facts that it has been over 5 years since the appearance of symptoms and conventional treatments was not effective for this patient, the BCI training system for focal hand dystonia is a great progress in the treatment.

On the other hand, Patient B showed no change in handwriting. The patient keeps capability to write stable letters even in pre-training condition. Therefore, we could not find any differences between pre- and post- training conditions. The feature of symptoms in the patient was slow writing. From the viewpoint of symptom, the neural background was actually very different between these participants, and this may cause the difference in the outcome of BCI intervention.

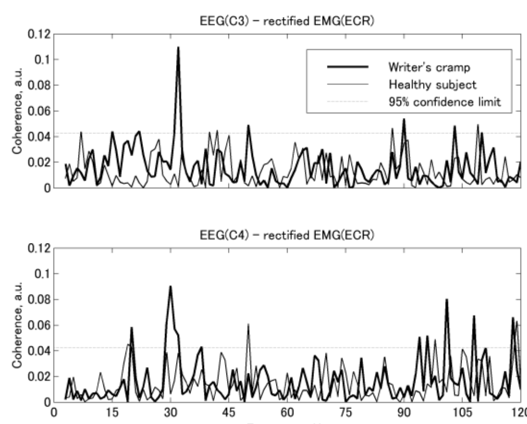

Figure 5. Coherence spectra between EEG and rectified ECR muscle EMG. (The upper row shows that EEG is recorded from left hemisphere (C3) and Lower row from right hemisphere (C4). The horizontal line denotes the 99% confidence limit. Thin and thick lines inidicate the data from a healthy paticipant and a focal hand dystonia patient, respectively.)

To date, the main stream of BCI research has aimed to let quadriplegia, stoke patients, or patients whose motor pathway was impaired learn motor control. Current study however showed another possibility to apply BCI system for patients with involuntary muscle contraction or neuronal overexcitation of the cortex such as dystonia patient by using visual feedback of abnormal EEG activity to reduce the activity. Next goals of this study are to reveal the relation between abnormal EEG activity and cortical excitation, and to add evaluation items to assess human capability of writing such as writing speed or hand force during holding a pen.

REFERENCES

[1] M. P. Sheehy and C. D. Marsden, “Writers' cramp-a focal dystonia,” *Brain*, vol. 105 (Pt 3), pp. 461–480, Sep. 1982.

[2] M. C. Ridding, G. Sheean, J. C. Rothwell, R. Inzelberg, and T. Kujirai, “Changes in the balance between motor cortical excitation and inhibition in focal, task specific dystonia,” *J. Neurol. Neurosurg. Psychiatr.*, vol. 59, no. 5, pp. 493–498, Nov. 1995.

[3] C. Preibisch, D. Berg, E. Hofmann, L. Solymosi, and M. Naumann, “Cerebral activation patterns in patients with writer's cramp: a functional magnetic resonance imaging study,” *J. Neurol.*, vol. 248, no. 1, pp. 10–17, Jan. 2001.

[4] E. Frasson, A. Priori, L. Bertolasi, F. Mauguière, A. Fiaschi, and M. Tinazzi, “Somatosensory disinhibition in dystonia,” *Mov. Disord.*, vol. 16, no. 4, pp. 674–682, Jul. 2001.

[5] C. Toro, G. Deuschl, and M. Hallett, “Movement-related electroencephalographic desynchronization in patients with hand cramps: evidence for motor cortical involvement in focal dystonia,” *Ann. Neurol.*, vol. 47, no. 4, pp. 456–461, Apr. 2000.

[6] Y. H. Sohn, N. Dang, and M. Hallett, “Suppression of corticospinal excitability during negative motor imagery,” *J. Neurophysiol.*, vol. 90, no. 4, pp. 2303–2309, Oct. 2003.

[7] J. Kalcher and G. Pfurtscheller, “Discrimination between phase-locked and non-phase-locked event-related EEG activity,” *Electroencephalogr Clin Neurophysiol*, vol. 94, no. 5, pp. 381–384, May 1995.

[8] T. Solis-Escalante, G. R. Müller-Putz, G. Pfurtscheller, and C. Neuper, “Cue-induced beta rebound during withholding of overt and covert foot movement,” *Clin Neurophysiol*, vol. 123, no. 6, pp. 1182–1190, Jun. 2012.

[9] Y. Hashimoto, J. Ushiba, A. Kimura, M. Liu, and Y. Tomita, “Correlation between EEG-EMG coherence during isometric contraction and its imaginary execution,” *Acta Neurobiol Exp (Wars)*, vol. 70, no. 1, pp. 76–85, 2010.

[10] J. R. Rosenberg, A. M. Amjad, P. Breeze, D. R. Brillinger, and D. M. Halliday, “The Fourier approach to the identification of functional coupling between neuronal spike trains,” *Prog. Biophys. Mol. Biol.*, vol. 53, no. 1, pp. 1–31, 1989.

[11] T. Mima and M. Hallett, “Corticomuscular coherence: a review,” *J Clin Neurophysiol*, vol. 16, no. 6, pp. 501–511, Nov. 1999.

[12] L. Leocani and G. Comi, “Movement-related event-related desynchronization in neuropsychiatric disorders,” *Prog. Brain Res.*, vol. 159, pp. 351–366, 2006.

[13] S. H. Jin, P. Lin, S. Auh, and M. Hallett, “Abnormal functional connectivity in focal hand dystonia: mutual information analysis in EEG,” *Mov. Disord.*, vol. 26, no. 7, pp. 1274–1281, Jun. 2011.