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Analysis of Extrinsic and Intrinsic Factors Affecting Event Related Desynchronization Production

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Abstract— **Recently there has been an increase in the number of stroke patients with motor paralysis. Appropriate re-afferent sensory feedback synchronized with a voluntary motor intention would be effective for promoting neural plasticity in the stroke rehabilitation. Therefore, BCI technology is considered to be a promising approach in the neuro-rehabilitation. To estimate human motor intention, an event-related desynchronization (ERD), a feature of electroencephalogram (EEG) evoked by motor execution or motor imagery is usually used. However, there exists various factors that affect ERD production, and its neural mechanism is still an open question. As a preliminary stage, we evaluate mutual effects of intrinsic (voluntary motor imagery) and extrinsic (visual and somatosensory stimuli) factors on the ERD production. Experimental results indicate that these three factors are not always additively interacting with each other and affecting the ERD production.**

I. Introduction

Because of rapid aging of the society or a dietary change, there has been an increase in the number of stroke patients. To recover from a motor paralysis, an appropriate motor rehabilitation therapy is crucial. To promote neural plasticity during the therapy, patients should not only perform passive range of motion exercises, but also experience a re-afferent sensory feedback synchronized with their voluntary motor intention [1], likewise healthy persons do.

Although severely impaired stroke patients cannot express their voluntary motor intention, recently brain–computer interface (BCI) technology has enabled interpretation of the intention directly from their brain activities (e.g. electroencephalogram). Especially, an event-related desynchronization (ERD), decrease of a specific brain rhythm around sensorimotor area, has been widely used for decoding their intention [2], [3], [5], [6], [7], [8], [11], [12]. ERD is known as an EEG feature that is observed in a human sensorimotor cortex area when an actual motor execution or motor imagery occurs. Therefore it can be used as an endogenous BCI without any external stimuli, unlike a exogenous BCI (SSVEP or P300) [7]. In addition it is known that the topographical region of the ERD production corresponds to a homuncular organization in the human primary motor area [6]. For example motor imagery for the foot can cause ERD around the center of the motor area (Cz in the international 10-20 system). Furthermore, ERD can be observed in a narrow frequency band specific to each body part, e.g. 9–13 Hz for the hand and 18–23 Hz for the foot. It is also known that voluntary ERD production is innately difficult and this ability can be improved with a neuro-feedback training [3], [6]. Also some research reported that observing a video that includes human movement (e.g. a moving hand) induces ERD in healthy subjects without any training [9], [10]. Moreover, other research has found that somatosensory stimulus by functional electric stimulation (FES) can modulate the motor imagery-based ERD production [2], [8], [11].

Consequently, various factors affect the ERD production; however its neural mechanism is still an open question. As a preliminary stage, we systematically investigate mutual effects of intrinsic (i.e. motor imagery) and extrinsic (i.e. visual and somatosensory stimuli) factors on the ERD production.

II. Methods

A. Subjects

Six healthy young volunteers (five male and one female, mean age was 22.0±1.0 years) participated in the following experiments with written informed consent. All were right-handed and had no neurological disorders according to self report. Protocols of the experiment were approved by the ethical committee of Tokyo University of Agriculture and Technology, Japan.

B. Experimental system

As shown in Fig. 1, subjects were seated in a comfortable high-back chair with a foot rest. An LCD monitor was placed on an angled table located over their thighs, and they were asked to adjust the tilt angle to be able to see the video on the monitor (Fig. 2). We used five Ag/AgCl electrodes to take electroencephalogram measurements (g.ACTIVEelectrode, g.tec medical engineering, Austria) and these were placed to cover the sensorimotor area considered to be involved in motor control of lower extremity, which corresponds to Cz and its surrounding (FCz, CPz, C1, and C2) in the international 10-20 system. Reference and ground electrodes were located at left ear lobule and Fpz, respectively. The EEG signals were amplified using a multi-telemeter system (WEB5500, NIHON KOHDEN Co., Japan) and recorded using a 16-bit A/D-D/A converter (AIO-160802, CONTEC,

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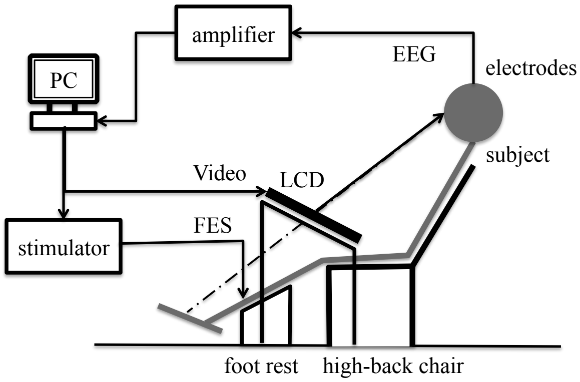

Fig. 1. The experimental system.

Fig. 2. The visual stimulus displayed on an LCD monitor in the first-person's perspective.

Japan) with sampling rate 256 Hz. A band-pass filter (0.1–100 Hz) was applied during measurement. An electrical stimulator (SEN08203, NIHON KOHDEN Co., Japan) and an isolator (SS-104J, NIHON KOHDEN Co., Japan) were used for functional electrical stimulation (FES).

C. Procedure

To clearly understand the differences or mutual relationships among intrinsic (voluntary motor imagery) and extrinsic (visual and somatosensory stimuli) factors and their effects on the ERD production, we measured an EEG signal of each subject under seven possible combinations of the three factors as shown in Table I. In the video conditions, the subjects saw a video including a dorsiflexion of someone's left foot from the first-person's view point (see Fig. 2). To promote having an illusion as if the video was perceived as their own movement, they were asked to wear the same trousers. Under the FES conditions, the subjects received electrical stimulus (50 Hz rectangular pluses with 300μs duration, maximum amplitude (under 28 mA) was adjusted individually) to *tibialis anterior* muscle of his/her left leg.

TABLE I
CONDITIONS OF TASK PERIOD.

Conditions	Video	FES	Motor Imagery (MI)
Video only (V)	o	-	-
Video and FES (VF)	o	o	-
Video, FES, and MI (VFI)	o	o	o
Video and MI (VI)	o	-	o
Motor Imagery only (I)	-	-	o
FES and MI (FI)	-	o	o
FES only (F)	-	o	-

Furthermore, in the motor imagery conditions, the subjects were instructed to imagine dorsiflexion of their left leg.

In the experiment, EEG signals were recorded according to the experimental design shown in Fig. 3. As illustrated, each trial consisted of rest and task periods, and the rest period was randomly assigned to last for 5.0–10.0 s, while the task period lasted for 5.0 s. For ease of following explanation we dubbed the moment that the task period began as "cue onset" and we analyzed the EEG signals sampled just before and after the cue onset. During the rest period, subjects were asked to take a rest while gazing at a fixation circle on the screen, however in the video conditions, a still image of the video (i.e. someone's lower extremities) was displayed instead. Conversely, subjects were exposed to one of the seven conditions in the task period. The trial was repeated 30 times for each condition. The order of experimental conditions were randomized among subjects.

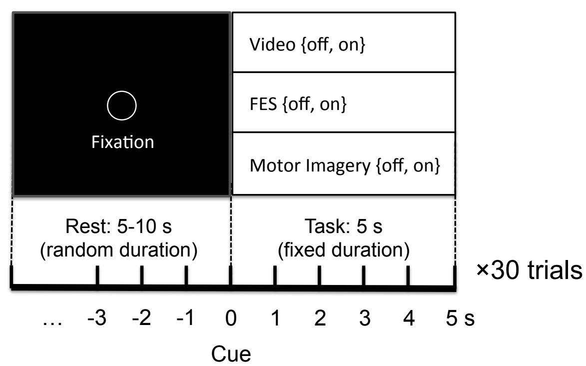

Fig. 3. Task design showing the time intervals for the experiment.

D. Signal Processing

To detect the ERD characteristic the EEG measurements were processed as follows: First, the trials with artifacts were discarded by the empirical rule. After that, raw EEG signals were filtered by several band-pass filters with a narrow and overlapped bandwidth (4 Hz) every 1000 ms time window (256 samples) to ascertain the frequency property around the mu and beta bands (5–33 Hz). The filtered signals were squared and time-averaged within each time window. This process was repeated every 125 ms in order to maintain a smooth change of the signal power. After this process we obtained a time–frequency map of the signal power for each condition.

To evaluate the ERD production under each condition, we further calculated decreasing rate of the signal power in each frequency band using the following equations [4]:

$$\bar{P}^{(i)}(f,t) = \frac{1}{N}\sum_{n=0}^{N} P^{(i)}(f,t+n\Delta T), \quad (1)$$

$$\bar{P}(f,t) = \frac{1}{M}\sum_{i=1}^{M} \bar{P}^{(i)}(f,t),$$

$$ERD(f,t) = \frac{\bar{P}(f,t) - \bar{P}_{rest}(f)}{\bar{P}_{rest}(f)} \times 100, \quad (2)$$

where, $P^{(i)}(f,t)$ is the signal power of i_{th} trial at frequency f and time t. Moreover, M, N and ΔT correspond to the number of trials, sample size in the time window, and sampling period, respectively. In fact we used equation (2) to calculate ERD, i.e. decreasing rate of the averaged signal power between the reference in the preceding rest period (it corresponds to 2 s duration just before the cue onset, and it is denoted as $\bar{P}_{rest}(f)$ in the equation) and each time window in the task period ($\bar{P}(f,t)$). Furthermore we evaluated variance of the averaged signal power ($\bar{P}^{(i)}(f,t)$) between 2 s before and after the cue onset.

III. Result

A. Time-frequency map of ERD

Fig. 4 shows the time–frequency maps of ERD for all subjects under seven conditions. Each graph demonstrates temporal characteristic of the signal power before 2 s and after 3 s of the cue onset represented as "0" in the figure. Because it shows decreasing rate of the averaged signal power calculated by equation (2), negative and dark blue regions in these graphs represent the more stronger ERD.

B. Statistical analysis of ERD

Table II shows results of statistical analysis of the average ERD production for all subjects and conditions with respect to the three frequency bands (15–20, 20–25, and 25–30 Hz). Each cell in the table represents whether the averaged signal power between 2 s before and after the cue onset in each condition has a statistical significance. For the analysis, we used a paired t-test. In the table, two asterisks ($**$) and an asterisk ($*$) indicate 1% ($p < 0.01$) and 5% ($p < 0.05$) significance, respectively.

TABLE II

Statistical analysis of ERD production for all subjects and conditions (Top: 15–20 Hz, Middle: 20–25 Hz, Bottom: 25–30 Hz).

15-20 Hz	V	VF	VFI	VI	I	FI	F
subject A	n.s.	n.s.	n.s.	*	*	n.s.	*
subject B	**	*	n.s.	*	n.s.	n.s.	n.s.
subject C	**	*	n.s.	n.s.	n.s.	**	*
subject D	**	**	**	**	*	*	**
subject E	**	*	*	n.s.	*	**	n.s.
subject F	n.s.	n.s.	n.s.	**	n.s.	**	**

20-25 Hz	V	VF	VFI	VI	I	FI	F
subject A	**	**	n.s.	**	n.s.	n.s.	**
subject B	**	**	n.s.	*	n.s.	n.s.	n.s.
subject C	**	*	n.s.	n.s.	n.s.	n.s.	n.s.
subject D	**	**	**	**	**	*	n.s.
subject E	**	**	**	*	**	*	n.s.
subject F	*	*	**	**	**	n.s.	*

25-30 Hz	V	VF	VFI	VI	I	FI	F
subject A	**	*	**	n.s.	**	n.s.	**
subject B	n.s.	**	n.s.	n.s.	n.s.	**	*
subject C	**	n.s.	**	**	**	**	**
subject D	**	**	**	**	**	**	**
subject E	**	*	**	n.s.	**	**	n.s.
subject F	*	n.s.	**	**	n.s.	**	*

** ($p < 0.01$) * ($p < 0.05$)

IV. Discussion

From the experimental results we found that condition F, where subjects received only FES without video and motor imagery had small effects on ERD production. This implies that a somatosensory stimulus alone cannot affect brain activity in a sensorimotor cortex, and ERD production is related to a re-afferent sensory stimulus. Therefore we may not be able to expect that the condition contributes to the neuro-rehabilitation.

On the other hand, subjects D, E and F showed significant ERD in middle frequency band (i.e. 20–25 Hz) just after the cue onset under conditions I, FI, VFI, and VI, in which subjects were instructed to have motor imagery. As has been noted, ERD arisen by a foot movement/motor imagery is considered 18–23 Hz. This result implies that these subjects originally had an ability to modulate their brain pattern by foot motor imagery. Although the others (i.e. subjects A, B, and C) might demonstrate ERD in certain trials and/or a specific narrow frequency band, it was not reflected in the averaged decreasing rate. Thus it seems that voluntary ERD production is innately difficult without any neuro-feedback training.

Furthermore we confirmed that the conditions observing a video and without having motor imagery (i.e. conditions V and VF) were commonly connected with the ERD production, although their corresponding frequency bands were different for each subject. Therefore the visually induced ERD can be considered innate and independent of individuals. However, condition VFI showed the same tendency with the motor imagery conditions (I and FI). It is suggested that a certain insufficient way of motor imagery (e.g. subject A, B, and C did) suppresses the effect of the visually induced ERD. This implies that these three factors are not always additively interacting with each other and affecting the ERD production.

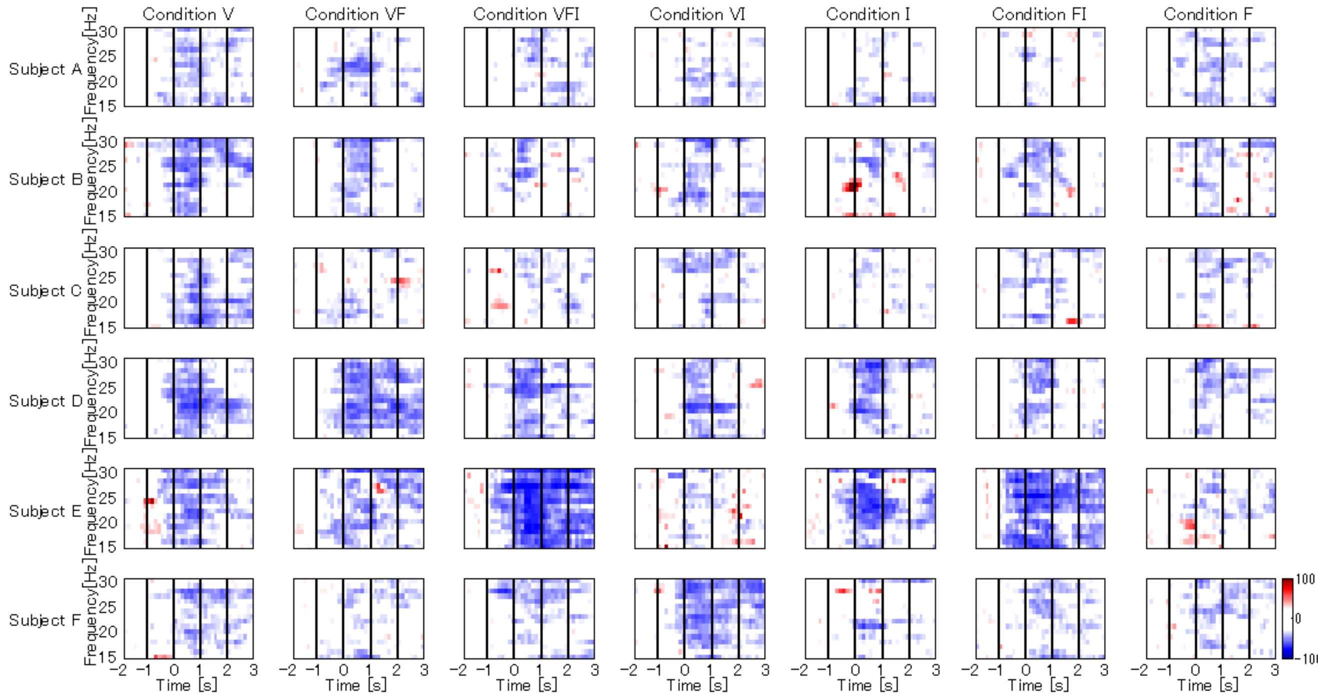

Fig. 4. Time–frequency maps of ERD for all subjects and conditions.

V. CONCLUSION

In the paper, we evaluated mutual effects of intrinsic (voluntary motor imagery) and extrinsic (visual and somatosensory stimuli) factors affecting the ERD production. The experimental results obtained here are follows: (1) Somatosensory stimulus (FES) alone might not affect the brain activity in the sensorimotor cortex. (2) Observing a video includes human movement from first-person's perspective is commonly affecting on ERD production, although ERD has been considered as an EEG feature for endogenous BCI without any external stimuli. (3) Under the motor imagery conditions, a voluntary ERD production is dependent on individuals. It seems to be innately difficult without any neuro-feedback training. (4) The three factors on which this research focused do not always additively interact with each other, there exists a complicated relationship.

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