Feeling of Bodily Congruence to Visual Stimuli Improves Motor Imagery Based Brain-Computer Interface Control

Junichi Ushiba, Shotaro Miyashita, Takashi Ono, Koji Aono, Mitsuhiko Kodama and Yoshihisa Masakado

Abstract Motor imagery based Brain-Computer Interface (BCI) utilizes an electrophysiological phenomenon of EEG power decrease in alpha frequency band, but its larger inter-subject variability limits the practical use. Here we tested three types of visual feedback objects in BCI from abstract to realistic scenarios during motor imagery to see its effect on self-induced changes of EEG power decrease. Double case study in hemiplegic stroke participants was also conducted to check its feasibility as neuro-facilitatory technique on the motor system. We found that a first person perspective of realistic visual feedback, which copies the participant's mental image, assisted the user to perform motor imagery resulting in generation of large EEG power decrease. The same result was found also in hemiplegic stroke patients. This study has clear implications for both the mechanism of mental process of motor imagery and the influence of feedback type on BCI performance.

1 Introduction

Sensorimotor rhythm (SMR) including a dominant 8–13 Hz component in scalp EEG is observed over the sensorimotor cortex (SM1). Event-related desynchronization (ERD), which is defined by amplitude attenuation of SMR, is observed during motor imagery, accompanied by the increase of corticospinal tract

This work was supported by the Japan Agency for Medical Research and Development (AMED) under the projects of Strategic Research Program for Brain Sciences and Development of Medical Devices and Systems for Advanced Medical Services, and Japan Society for the Promotion of Science (JSPS) Graint-in-Aid for Scientific Research C (16K01469).

J. Ushiba (✉) · S. Miyashita · T. Ono
Faculty of Science and Technology, Keio University, Kanagawa, Japan
e-mail: ushiba@bio.keio.ac.jp

K. Aono · M. Kodama · Y. Masakado
Department of Rehabilitation Science, Tokai University School of Medicine, Kanagawa, Japan

J. Ibáñez et al. (eds.), *Converging Clinical and Engineering Research on Neurorehabilitation II*, Biosystems & Biorobotics 15,
DOI 10.1007/978-3-319-46669-9_147

excitability. Repetition of self-regulated ERD in a Brain-Computer Interface (BCI) context has been therefore used as a neuro-facilitatory conditioning of the motor system [1].

Although ERD increase by motor imagery based BCI training has been promoted motor functional recovery in severe hemiplegia due to stroke [1], larger inter-subject variability limits the practical use of BCI and its rehabilitation effectiveness. Approaches to improve the inter-trial reproducibility of ERD has been therefore long explored.

Giving a highly effective visual feedback is one possible approach for accomplishing these objectives. For instance, there is some evidence that a rich visual representation of the feedback signal, e.g., in the form of a 3-dimensional video game or virtual reality environment enhances the learning process in a BCI task. This may be since employing rather realistic and engaging feedback scenarios, which are closely related to the specific target application, assists the user to perform motor imagery. If the effects of forms of visual feedback on generation ERD were systematically clarified, a clearer framework of understanding the neuropsychological mechanism of motor imagery accompanied with ERD, as well as facilitating ERD for establishment of practical BCI.

The present study tested the hypothesis that the reactivity of SMR during the complex interplay between motor imagery and feedback processing is influenced by the consistency of 'imaging object' and 'reacted object'. In the experiment, three types of feedback objects were prepared; an abstract bar moving horizontally (BAR), a third person perspective of realistic hand animation constructed from the participants' hand picture (HAND), and a first person perspective of same realistic hand animation (MIRROR). The participants tested all three feedbacks in random order within the same experimental day, and performed hand motor imagery with maximum effort in any types of feedbacks. Since ERD shows larger inter-subject variability, immediate effects of feedback on ERD were compared within the subjects to minimize the between-group bias. The hypothesis of the present study is that a first person perspective of realistic visual feedback, which copies the participant's mental image, assists the user to perform motor imagery resulting in generation of large ERD. This study has clear implications for both the mechanism of mental process of motor imagery and the influence of feedback type on BCI performance.

2 Methods

Ten healthy right-handed subjects (aged 23.8 ± 1.0 years; 10 men) participated this study. All participants were initially naive to the experiment and gave informed consent after the experimental procedure had been explained to them. The experimental protocol described below was in accord with the Helsinki Declaration and was approved by the ethical committee of Keio University and Tokai University.

The participants performed to image wrist extension of the dominant (right) side in a series of randomly ordered three feedback sessions. Each trial started with the presentation of the word “Rest” at the monitor. One second later, a 1 s period during which a character ‘Ready’ presented. After representing the word “Image”, the participants were instructed to imagine performing wrist extension. They had to perform the motor imagery for 5 s, until the word “Image” was disappeared. After a short pause, the next trial started. Each run consisted of 20 trials, and two runs with few minutes rests were recorded for each participant. Surface electromyogram was recorded over the right extensor carpi radialis muscle throughout the experiment, and used to confirm no overt contraction (<50 μVpp).

One session employed “BAR” visual feedback. Following the time scheme and cue described above, a continuously moving feedback bar (according to their ERD caused by the required motor imagery) was displayed on a screen (Fig. 1a). It appeared 0.5 s later than the cue and was presented over a 4-s period. The participants’ task was to extent the bar horizontally toward the right monitor edge and

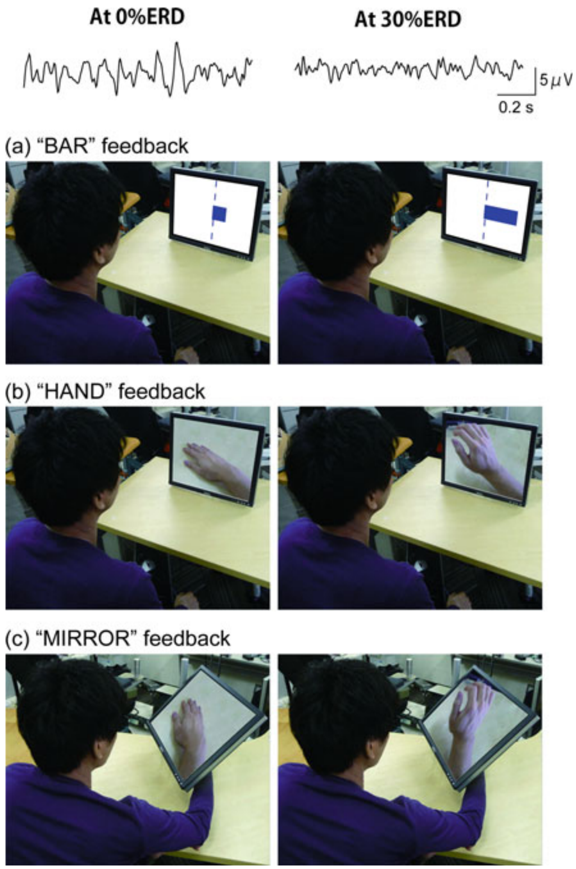

Fig. 1. Feedback types of BCI. **a** “BAR” feedback, **b** “HAND” feedback, and **c** “MIRROR” feedback

to keep it as long as possible in the correct half of the screen. Participants were informed that hand motor imagery would shift the bar.

The second session employed "HAND" feedback, a third person perspective of realistic hand animation constructed from the participants' hand picture, where a right wrist was moving to extend (according to their ERD caused by the required motor imagery) (see Fig. 1b). A video sequence of participant's self-paced wrist extension was digitized from the first person's perspective, prior to this experiment.

The third session employed "MIRROR" feedback. The form of the visual feedback is same as "HAND" feedback, but the display was placed over the participants' hand. The participants were therefore exposed their own hand-moving animation overlaying on their hand during motor imagery.

3 Results

Figure 2 depicts a representative dataset of ERD differences associated with the type of visual feedback (Participant H3). ERD was dominantly seen in 8–13 Hz in all cases, and was largest in the "MIRROR" (−68.9 ± 23.8 %ERD). Feedback with "HAND" showed a relatively large ERD (−59.1 ± 33.8 %ERD), whereas the "BAR" induced a small amplitude ERD (−11.9 ± 46.8 %ERD). ERD Bandwidth was slightly wider in "MIRROR" than in "HAND".

All the participants also showed largest ERD in the "MIRROR". "HAND" feedback induced a secondly large ERD, and the "BAR" only gained a small ERD. Multiple comparison of paired *t*-test by a Bonferroni correction for three feedback groups was performed, and confirmed that such difference was statistically significant ($p < 0.001$ between "BAR" and "MIRROR"; $p < 0.01$ between "HAND" and "MIRROR"; $p < 0.05$ between "BAR" and "HAND").

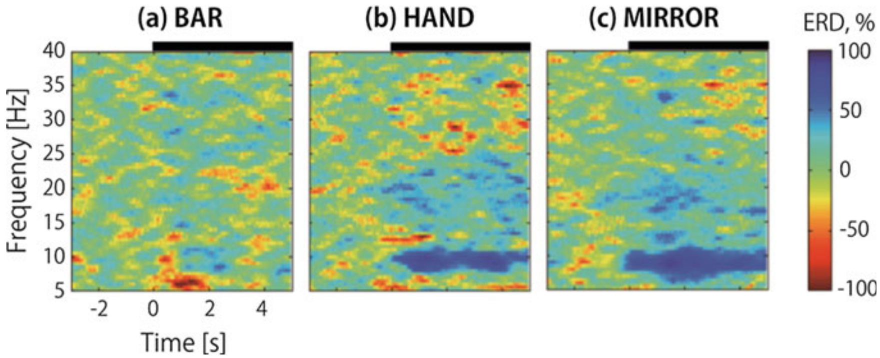

Fig. 2. A representative time-frequency representation of ERD

4 Discussion

Mirror neuron system is known to activate both when people perform an action and when they watch it being performed may exist in both monkeys and humans. The visuomotor mirror neurons may be thus activated by using realistic hand-picture feedbacks ("HAND" and "MIRROR"). Modulation of SMR has been recently linked to the activity of the human mirror neuron system, referring to an action observation/execution matching system, which is capable of performing an internal simulation of the observed action [2]. A functional correspondence between action observation, internal simulation or motor imagery and execution of the motor action has been proposed, thus ERD, which reflects the downstream modulation of SM1, may be strengthened in case of using realistic hand-picture feedback [3].

Due to these collateral factors, feedback-regulated motor imagery by means of a perspective view of realistic hand animation generates strong perception of illusory hand movement, and activates SM1 as a consequence, resulting in a large ERD. We also confirmed that the larger ERD was associated with the larger psychological score of body ownership with respect to the type of visual feedback, supporting this psychological hypothesis.

5 Conclusion

This study showed that motor imagery regulated with first-person perspective of realistic visual feedback induces prominent ERD over SM1. We suggest that the predominant process needed for hand motor imagery is mainly due to the first-person perspective of memory trace eliciting realistic visual stimuli. Since ERD has been considered as a biomarker of neural excitability in SM1, motor imagery regulated with realistic visual feedback may have a potentials use in neurorehabilitation.

References

1. J. Ushiba, S. Soekadar, Brain-machine interface rehabilitation in post-stroke hemiplegia. Prog. Brain Res. (in press)
2. J.A. Pineda, Sensorimotor cortex as a critical component of an 'extended' mirror neuron system: does it solve the development, correspondence, and control problems in mirroring? Behav. Brain Funct. **4** (2008). Article ID 47
3. C. Neuper, R. Scherer, S. Wriessnegger, G. Pfurtscheller, Motor imagery and action observation: modulation of sensorimotor brain rhythms during mental control of a brain-computer interface. Clin. Neurophysiol. **120**(2), 239–247 (2009)