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Effect of instructive visual stimuli on neurofeedback training for motor imagery-based brain–computer interface

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ABSTRACT

Event-related desynchronization (ERD) of the electroencephalogram (EEG) from the motor cortex is associated with execution, observation, and mental imagery of motor tasks. Generation of ERD by motor imagery (MI) has been widely used for brain–computer interfaces (BCIs) linked to neuroprosthetics and other motor assistance devices. Control of MI-based BCIs can be acquired by neurofeedback training to reliably induce MI-associated ERD. To develop more effective training conditions, we investigated the effect of static and dynamic visual representations of target movements (a picture of forearms or a video clip of hand grasping movements) during the BCI neurofeedback training. After 4 consecutive training days, the group that performed MI while viewing the video showed significant improvement in generating MI-associated ERD compared with the group that viewed the static image. This result suggests that passively observing the target movement during MI would improve the associated mental imagery and enhance MI-based BCIs skills.

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1. Introduction

The global incidence of stroke is increasing, along with the number of stroke patients living with significant physical impairments. To support and improve quality of life (QOL), various motor assistance devices have been developed, most of which aim to improve existing motor function rather than restore function to the paralyzed limbs. Brain Computer Interface (BCI) makes it possible to provide a communication channel from a human to a computer that directly translates brain activity into sequences of control commands. Such a device may give disabled people direct control over a neuroprosthesis or over computer applications as tools for communicating solely by their intentions that are reflected in their brain signals.

Recent work has shown that motor rehabilitation during the acute stages can decrease the effect of stroke (Cincotti et al., 2012), demonstrating that the rehabilitation exercise based on BCI neurofeedback enables a better engagement of motor areas with respect to motor imagery (MI) alone and thus it can promote neuroplasticity in brain regions affected by a cerebrovascular accident. It is important to consider motor learning in the context of brain plasticity. The signal flow in a motor control system can be described as: a motor command, generated in the motor area, that goes through the spinal cord and finally activates specific muscles. After muscle contraction, sensory feedback is transmitted to the somatosensory area in the cortex. This flow makes up the sensory-motor closed loop. However, stroke patients have difficulty learning specific motions because the loop is damaged. If a correlation between the motor command generation and the feedback signal to the somatosensory cortex can be achieved, this opens up the possibility for simulating the sensory-motor closed loop and thus enhance motor learning (Takahashi et al., 2012).

Therefore recent development of the BCI should be expected to activate sensorimotor regions and induce plasticity changes of the brain in neurorehabilitation (for review, see Pfurtscheller, Muller-Putz, Scherer, & Neuper (2008)). It has been postulated that the correlation of motor command generation and BCI may augment rehabilitation gains in stroke patients by activating corticomotor networks, providing sensory feedback to close the sensory motor loop.

One EEG feature that may be used to control BCIs is event-related desynchronization (ERD). Motor cortex ERD is defined as a relative decrease in EEG power within the alpha (8–13 Hz) and beta (14–26 Hz) bands that is correlated with both real movements and MI (Graimann, Allison, & Pfurtscheller, 2010; Pfurtscheller, 2001). An advantageous property of this ERD for BCI control is that it is somatotopic, e.g., right hand movement or MI of right hand movement may induce ERD in the EEG from the contralateral (left) sensorimotor cortex (Wolpaw, Birbaumer, Mcfarland, Pfurtscheller, & Vaughan, 2002). Therefore, the production of ERD from specific cortical regions may be used as a control cue for a range of movements. Furthermore, ERD can be internally generated, providing direct neural control over the BCI. In light of these characteristics, many have speculated that ERD can be used as the basis for an intuitive control interface for motor assistance (Leeb, Friedman, et al., 2007; Leeb, Lee, et al., 2007; Zhao et al., 2009) and neurorehabilitation methodology (Ono, Kimura, & Ushiba, 2013; Shindo et al., 2011; Takahashi et al., 2012).

To further facilitate the brain plasticity in clinical studies, it is crucial to detect the motor command generation in a single trial, Pfurtscheller, Brunner, Schlögl, and Lopes da Silva (2006) included event-related synchronization (ERS) as a neuronal marker to improve the classification of MI tasks on single trials. However, as described by Wolpaw et al. (2002), controlling ERD to reliably reflect appropriate mental images (like specific movements) is a difficult skill to master. Training programs for BCI control are further hampered by a lack of insight into the physiological mechanisms of ERD induction or control of ERD strength.

Neuper, Scherer, Reiner, and Pfurtscheller (2005) investigated the ERD during motor execution (ME), MI of own-movements (kinesthetic), motor observation (MO) and MI of someone else's movements (mental visualization), and they reported that the strongest ERD appeared when subjects imagined their own movements. In addition, Pfurtscheller, Scherer, Leeb, and Keinrath (2007) found that viewing a hand grasping movements on a head-mounted screen evoked a stronger ERD compared with that evoked by the image of a still cube, a moving cube or a still hand.