Proposing a Novel Feedback Provision Paradigm for Restorative Brain-Computer Interfaces

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Abstract. Restorative brain-computer interafces (BCIs) have been exploited by a number of BCI labs for the purpose of stroke rehabilitation. The results that are achieved with commonly used technology are rather promising, but inconsistent. In this abstract we propose a novel paradigm for restorative BCI designs, which is based on motor learning theory and the Hebbian learning rule. It is expected to enhance the degree of neuroplasticity in stroke patients.

Keywords: Restorative BCI, Feedback, Hebbian learning rule

1. Introduction

Stroke is a major cause of paralysis. In traditional stroke rehabilitation, repetitive rehearsal of motor actions is exploited with the aim that impaired neural paths become reorganized in the same way that they were established during early development of motor functions. This perspective is based on the activity-dependent plasticity concept [Koganemaru et al., 2010].

Considering the similarity between activity in the sensorimotor area of the human brain during motor imagery and that during motor execution, motor imagery has been suggested as an alternative modality for recovering impaired motor functions after stroke [de Vries et al., 2007]. There is some evidence that application of motor imagery in healthy subjects activates cortical excitability, which increases the amplitude of motor evoked potentials (MEP) in response to transcranial magnetic stimulation [Kasai et al., 1997]. This finding suggests that motor imagery can modulate corticospinal excitability in a similar manner to real motor practice.

However, motor imagery does not involve activation of target muscles and, as a result, does not result in any movement related sensory feedback. However, sensory feedback is critical for optimal motor learning and provides an important component for the modulation and fine-tuning of future planning of motor activities. Thus, in this paper we propose a novel method for providing sensory feedback during motor imagery in restorative BCI. In particular, we describe an approach for providing sensory feedback at a timing that will be optimal for practice-dependent learning based upon Hebbian learning rules. We anticipate that this approach will offer significantly improved therapeutic options for the rehabilitation of stroke patients.

2. Methods

A combination of proprioceptive and visual feedback is thought to be the optimum form of sensory feedback for motor functions [Ramos-Murguialday et al., 2012]. Even though there have been a number of trials providing such feedback for motor imagery based restorative BCI designs, there is no clear rationale provided for the latency used between motor imagery modulation and feedback provision [Ramos-Murguialday et al., 2012; Shindo et al., 2011].

There is evidence that the latency for the efferent route from the primary motor cortex (M1) to the contralateral median nerve is approximately 20 ms [Samii et al., 1998]. In addition, studies show that the required time for sensory feedback to travel from the median nerve to the contralateral M1 is approximately 25 ms [Stefan et al., 2000]. Thus the total time for a motor learning loop is thought to be around 45 ms. Presuming a critical role for the Hebbian learning rule, in practice-dependent motor learning, it is mandatory to provide sensory feedback during motor imagery based BCI training at an interval (i.e. 45 ms) similar to that of actual motor training.

2.1. Proposed design specifications

As the first 250-500 ms of motor imagery does not contain useful features regarding sensorimotor cortex activity [Pfurtscheller et al., 1999], the classification of EEG features is proposed to be carried out using windows of 750 ms length, which slide 20 ms at each classification update cycle. Thus the classifier update rate is defined to be 20 ms (in conformity with efferent latency from the M1 area to the median nerve). In the case of detection of the correct imagery by the classifier, stimulatory feedback must be provided. Therefore, a fast and real-time BCI system, with its total transfer time, signal processing and application delay as low as 20 ms is required.

We propose three channels of electroencephalogram (EEG) recordings to be used in this design to make classification update results available in the proposed short time frame.

Concerning the feedback modality, we propose visual and proprioceptive feedback through an orthosis such as the M-28 servomotor to flex 4 fingers of the subject for 1 degree every time that classifier detects the requested motor imagery based on the classification result, while having the subjects to look at their hand (to provide the complimentary visual feedback). A similar paradigm is described in [Ramos-Murguialday et al., 2012].

Regarding the trial duration, we propose to use 2 seconds of rest, followed by 1 second of preparation using showing a "+" sign on the monitor to the subject. Then by showing them an arrow pointing towards their target hand, we instruct them to perform the motor imagery task for 2 seconds.

As for the software platform, we propose BCI2000 to be used as our software platform for its fast and real time processing algorithms. For occurrence of Hebbian based plasticity it is crucial that patients keep imagining 4-finger flexion for a period of 2 seconds, continuously. Regarding the fast proposed update rate (20 ms), sampling frequency is defined to be 500 Hz so as to provide enough sampling data for signal processing.

3. Discussion

We propose a novel design for a restorative BCI system for stroke rehabilitation that its timing is similar to that of motor learning. Subjects are instructed to perform motor imagery and then every 20 ms, they are provided with a proprioceptive/visual feedback. The provided feedback is expected to reach the M1 area after 25 ms and, if the subject keeps modulation of motor imagery, at the time of feedback arrival in the M1 area, it is expected to strengthen the connection between S1 and M1. This may provide the basis for reorganization of neural networks involved in the task leading to improvements in performance. Fig. 1 demonstrates our proposed timing.

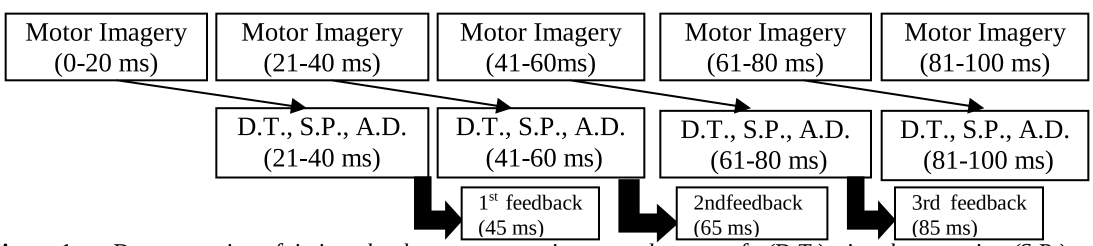

Figure 1. *Demonstration of timing plan between motor imagery, data transfer(D.T.), signal processing (S.P.), and application delay (A.D.) and their consequent feedback arrival time to M1. It is clear that 45 ms after each 20 ms portion of motor imagery, its correspondent feedback reaches M1. Thus assuming continuous modulation of motor imagery by subject, enhancement in plasticity is expected upon Hebbian learning rules.*

References

de Vries S, Mulder T. Motor imagery and stroke rehabilitation: a critical discussion. *J Rehabil Med*, 39(1):5-13, 2007.

Kasai T, Kawai S, Kawanishi M, Yahagi S. Evidence for facilitation of motor evoked potentials (MEPs) induced by motor imagery. *Brain Res*, 744(1):147-150, 1997.

Koganemaru S, Mima T, Thabit MN, Ikkaku T, Shimada K, Kanematsu M, Takahashi K, Fawi G, Takahashi R, Fukuyama H, Domen K. Recovery of upper-limb function due to enhanced use-dependent plasticity in chronic stroke patients. *Brain*, 133(11):3373-3384, 2010.

Pfurtscheller G, Neuper C, Ramoser H, Müller-Gerking J. Visually guided motor imagery activates sensorimotor areas in humans. *Neurosci Lett*, 269(3):153-156, 1999.

Ramos-Murguialday A, Schurholz M, Caggiano V, Wildgruber M, Caria A, Hammer EM, Halder S, Birbaumer N. Proprioceptive feedback and brain computer interface (BCI) based neuroprostheses. *PLoS One*, 7(10):e47048, 2012.

Samii A, Luciano CA, Dambrosia JM, Hallett M. Central motor conduction time: reproducibility and discomfort of different methods. *Muscle Nerve*, 21(11):1445-1450, 1998.

Shindo K, Kawashima K, Ushiba J, Ota N, Ito M, Ota T, Kimura A, Liu M. Effects of neurofeedback training with an electroencephalogram-based brain-computer interface for hand paralysis in patients with chronic stroke: a preliminary case series study. *J Rehabil Med*, 43(10):951-957, 2011.

Stefan K, Kunesch E, Cohen LG, Benecke R, Classen J. Induction of plasticity in the human motor cortex by paired associative stimulation. *Brain*, 123(3):572-584, 2000.