Neuroscience Letters 617 (2016) 156–159

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Research paper

The role of the cerebellum in motor imagery

Bülent Cengiz*, H. Evren Boran

Motor Control Laboratory, The Clinical Neurophysiology Division of the Department of Neurology, Gazi University Faculty of Medicine, Ankara, Turkey

HIGHLIGHTS

- Motor imagery is influenced by cerebellar activity.
- Cerebellum has an *inhibitory* modulatory effect of motor imagery.
- The effect of cerebellum on motor imagery can be modulated by cerebellar transcranial direct current stimulation.

ARTICLE INFO

Article history:
Received 16 August 2015
Received in revised form 23 January 2016
Accepted 25 January 2016
Available online 11 February 2016

Keywords:
Motor imagery
Cerebellar transcranial direct current stimulation
Cerebellar excitability
Motor excitability

ABSTRACT

Objective: Although it is well documented that the cerebellum plays a role in motor imagery (MI), its exact role in MI is still obscure. Since motor imagery and execution of movement share common pathways, and the cerebellum has an inhibitory effect on the motor cortex, we speculated that the cerebellum also has an inhibitory role on MI.
Methods: To test this hypothesis, 12 healthy individuals aged 27–47 years (mean age 33.3 years) were enrolled in the study. Subjects were asked to imagine two different tasks, one complex (MI-c) and one simple (MI-s) motor task. The intensity of anodal cerebellar transcranial direct current stimulation (ctDCS) was set at 2 mA for 20 min. Sham ctDCS consisted of 30 s current stimulation.
Results: MI-s resulted in significantly increased log MEP amplitude during MI, compared with control MEP amplitude,($p = 0.000$). The increase in log MEP amplitude during MI disappeared after anodal ctDCS. Before sham ctDCS, both MI-s and MI-c resulted in log MEP amplitude increases ($p = 0.000$). This facilitator effect of both MI-c and MI-s on log MEP amplitude was also persistent after sham ctDCS ($p = 0.000$).
Conclusions: The study demonstrates for the first time that the cerebellum has an inhibitory effect on MI.
Significance: Combining ctDCS with MI significantly modulates corticomotor excitability.

1. Introduction

Motor imagery (MI) is defined as executing a motor task mentally without any motor output. In this condition, the subject mentally simulates a given action. Results from a wide range of studies indicate that MI shares similar frameworks to those that are involved in programing and preparing an actual movement [1].

Functional magnetic resonance imaging and positron emission tomography provide strong evidence concerning the cerebral structures activated during MI (reviewed in Refs. [2,3]). The primary motor cortex, premotor cortex, the supplementary motor area, parietal lobe, the basal ganglia and the cerebellum are involved in MI [4–6]. Although it is less significant than execution of the imagined movement [7], activation of the corticospinal network during MI has been documented in previous studies. Transcranial magnetic stimulation (TMS) studies have revealed that motor evoked potential (MEP) amplitudes increase during MI in muscles involved in the MI [8–12].

The cerebellum gives information from the contralateral motor cortex (M1), sensory cortex and spinal cord, and plays a role in motor control of movement. The corticoponto-cerebellar tract carries information about cortical control of movement. Outputs from the cerebellum to the motor cortex are mainly transported via the dentathotalamocortical pathway, which has a facilitatory effect on the motor cortex. In addition, the cerebellum has an internal inhibitory pathway. Purkinje cells of the cerebellar cortex inhibit the dentate nucleus, and activation of Purkinje cells results in disfacilitation of the motor cortex.

The cerebellum is not only activated during execution of movement but also activated during MI [4,5]. It has been suggested that the activation of the cerebellum during MI reflects an inhibitory

* Corresponding author. Gazi University Faculty of Medicine, Department of Neurology, Beşevler, 06500 Ankara Turkey.
E-mail address: bcengiz@gazi.edu.tr (B. Cengiz).

http://dx.doi.org/10.1016/j.neulet.2016.01.045
0304-3940/

mechanism that prevents the efferent impulses triggered through imagery to reach the medullar and muscle levels [13]. To test this hypothesis which is activation of cerebellum inhibits MI, we altered cerebellar excitability by means of transcranial direct current stimulation (ctDCS) to investigate its effect on MI. We used anodal ctDCS to increase cerebellar activity during MI and hypothesized that with this modulation of cerebellar excitability its inhibitory effect on MI would increase.

2. Method

2.1. Subjects

Twelve right handed healthy individuals (two female) aged 27–47 years (mean age 33.3 years) without a systemic or neurologic disease were enrolled in the study. All participants provided written informed consent and the study was approved by the Ankara Numune Hospital Human Research Ethics Committee.

2.2. The imagined tasks

In order to determine whether the complexity of the MI is a parameter in terms of the cerebellum—MI interaction we used two diferrent tasks for motor imagery. Subjects were asked to imagine performing two distinct motor tasks. Abduction of the index finger was the simple MI task (MI-s), whereas counting rosary beads was the complex MI task (MI-c). In the MI-s task, the subject was asked to imagine abduction and adduction of his/her right index finger on Table repeatedly at a moderate speed. In the MI-c task, the subject was instructed to imagine counting rosary beads with the right hand. This movement consisted of a rotating movement of the right index finger on each bead while the rosary was held between the first and third fingers. The required movements were demonstrated before the subjects imagined performing them. None of the subjects had previous experience of counting rosary beads. Electromyography (EMG) monitoring of the first dorsal interosseous (FDI) muscle was used to confirm complete muscle relaxation.

2.3. Cerebellar transcranial direct current stimulation

The tDCS device was a CE approved, battery-driven, constant current stimulator. ctDCS was delivered via two sponges embedded in a saline-soaked solution. The active electrode was 5×5 cm (current density 0.08 mA/cm^2), while the reference electrode was 9×5 cm (current density 0.044 mA/cm^2). To get more focal tDCS we used a large reference electrode [14]. To detect the effect of the cerebellum on left motor cortex excitability we placed the active electrode on the right cerebellar cortex, 3 cm lateral to the inion. The reference electrode was positioned on the right buccinator muscle [15]. The intensity of anodal stimulation was set at 2 mA for 20 min. Sham ctDCS consisted of 30 s current stimulation. ctDCS was performed during MI tasks. Ramp up and ramp down was over 20 s.

2.4. Transcranial magnetic stimulation

TMS was performed using a 90 mm circular coil oriented to induce current flow in a posterior-anterior direction. The coil was connected to a Magstim 200 monophasic stimulator (Magstim, Whitland, UK). The coil was adjusted so that the optimal position for the MEP was obtained from the FDI muscle. EMG signals were filtered (30 Hz to 3 kHz) and sampled at 10 kHz. Recordings were taken from the right FDI muscle using 10 mm Ag–AgCl surface electrodes. MEP amplitudes were recorded by using Signal software and CED 1401 hardware (Cambridge Electronic Design, Cambridge, UK).

2.5. Experimental procedures

MEP amplitude, resting motor threshold (rMT) and silent period (SP) were measured according to the recommendations of the IFCN committee [16]. Subjects were seated in a comfortable reclining chair. After defining a threshold of 1 mV MEP, basal MEP amplitude was calculated as the average value of 30 MEPs that resulted in stimulation of the contralateral motor cortex at this stimulation intensity, at a 0.2 Hz rate with fixed intervals during the resting state of the muscle. This stimulation intensity was kept constant during the study. The effect of MI on motor cortical excitability was measured by MEP amplitude changes. Subjects were asked to imagine one of the two tasks and as they imagined the task the contralateral motor cortex was stimulated to elucidate the effect of MI on MEP amplitude. The average value of 30 MEPs during MI was calculated. MEP amplitude is measured as peak-to-peak amplitude. Imaging ratio (IR) was defined as: average MEP amplitude $_{(\text{during imaging})}$/average MEP amplitude $_{(\text{resting})}$. The same protocol was repeated during rMT and SP measurements. rMT was defined as the threshold to elicit at least three of five MEPs $\geq$50 μV.

After this protocol, each subject underwent two different cerebellar modulation studies: anodal ctDCS and sham ctDCS. IR, rMT and SP were also measured immediately after ctDCS. The order of cerebellar modulation was counterbalanced for each individual. The interval between experiments (anodal ctDCS session and sham ctDCS session) was at least 1 week. The patient was blind to type of the ctDCS. The study was designed with ordered sessions which anodal ctDCS was applied at first session and sham ctDCS was applied at second session.

2.6. Statistical analysis

Logarithmic transformation was applied to MEP amplitude values in order to normalize data distribution before ANOVA. Time-dependent changes of the parameters during MI and ctDCS were assessed using repeated measures analysis of variance (ANOVA). The ANOVA model included the factors imagery (IR after MI-s and after MI-c), time (before ctDCS vs after ctDCS) and stimulation (anodal vs sham stimulation). Conditional on a significant F value, post hoc paired-sample t-tests with Bonferroni correction were performed to explore the strength of the main effects and the patterns of interaction between experimental factors. P values <0.05 were considered statistically significant.

3. Results

The mean values of the variables are shown in Table 1. When IR was compared with regard to imagery type, and stimulation with respect to stimulation time, three ways repeated measures ANOVA revealed a significant main effect of imagery ($F_{(1,88)} = 13.33$, $p = 0.001$), stimulation ($F_{(1,99)} = 7.25$, $p = 0.017$) and time ($F_{(1,88)} = 4.91$, $p = 0.045$). There was no interaction between imagery, time and stimulation ($p = 0.2$).

3.1. Effect of MI on MEP amplitude

Before anodal ctDCS, repeated ANOVA revealed that MI-s resulted in significantly increased mean log MEP amplitude during MI, compared with control mean log MEP amplitude ($F_{(2,22)} = 16.2$, $p = 0.000$), this was not the case for MI-c.

3.2. Effect of anodal ctDCS on MI

The statistically significant increase in mean log MEP amplitude during MI-s disappeared after anodal ctDCS (Fig. 1).