Functional TMS mapping during sensorimotor integration task

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***Abstract*—In the present research, we studied spatiotemporal influence of a single-pulse TMS on the process of sensorimotor integration. We considered how real and sham stimulation of the left or right premotor, motor or sensorimotor cortex, delivered 200 or 800 ms after the demonstration of a visual stimuli, affected response time of subjects during sensorimotor integration task. At this stage of the study, we found that a single TMS of the sensorimotor cortex, delivered 800 ms after stimulus presentation, increases response time.**

Keywords—sensorimotor integration, TMS, response time.

I. Introduction

Every day people are faced with many sensory signals that require a certain behavioral responses, including motor. Voluntary motor activity produced in response to specific external stimuli is possible due to the process of sensorimotor integration. At the cortical level, this process carried out due to the harmonious work of the sensory, motor and associative areas of the cerebral cortex. Passing a long way from sensors to different levels analyzers, information eventually enters the cortex multimodal associative sections and the primary motor cortex – the center of motor activity [1].

The process of sensorimotor integration is also being widely studied in medicine. Such studies are aimed at determining the causes of impaired motor skills and sensory processing in various diseases [2-5], as well as developing methods of rehabilitation [6], including approaches with brain-computer interfaces [7] and transcranial magnetic stimulation (TMS) [8]. TMS is also used today as an effective method for mapping brain functions [9], especially the process of sensorimotor integration [10-11].

In this research, we study spatiotemporal influence of a single-pulse TMS on the process of sensorimotor integration. Since it involves both sensory and motor functions, we stimulated high relevant information processing areas of the brain – premotor, primary motor and sensorimotor cortex – at times when there two functions were activated. We assessed the contribution of TMS by response time (RT) on a sensorimotor task appearance on the screen, and by the number of mistakes were made by participants while performing these tasks.

II. Methods

A. Participants

Seventeen naive subjects (8 females, 9 males, age 19-27, right-handed) with no neurological diseases in history took part in this research. Participants were asked to avoid products with stimulating effect on psychomotor activity before the day of experiment. Volunteers did not have contraindications to TMS. The experimental procedure was approved by the local ethics committee of the Lobachevsky State University of Nizhny Novgorod.

B. Visual stimuli and sensorimotor task

Pictures of an abstract palm with one finger colored in red, number and direction arrow were presented to participants via computer monitor. A number and an arrow above the palm indicated how many fingers from colored one and in which direction (left or right) subject needed to count. Based on that information a subject needed to determine the target finger (Fig.1, green finger). With this finger, he had to press a button on a specially prepared keyboard as quickly as possible.

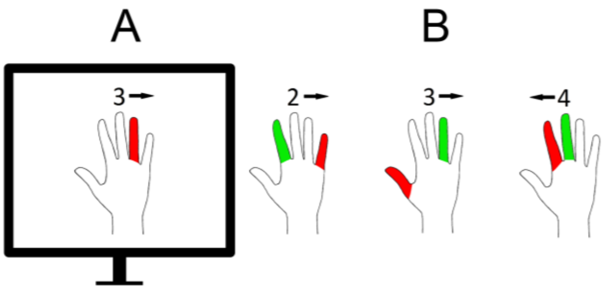

Fig.1. Visual stimuli. A – demonstration of a visual stimuli on a screen, B – some variants of sensorimotor task solutions (green finger – target)

We used only numbers 2, 3 and 4 since they represent the greatest difficulty for the assigned task. According to the pilot study, participants reacted on 1 and 5 significantly quicker than on 2, 3 and 4. Taking into account the variations of the elements (zero-point finger, number, direction), 30 variants of visual stimuli were obtained.

For each stimulus, we determined two parameters of the subject's behavioral response: RTs and errors. RTs were determined as time intervals from the moment of stimuli appearance to the moment when subject pressed a key. Errors were determined by comparing the stimuli with the subject's response finger.

C. Experimental session

During the experiment, participants were seated in a comfortable armchair at a distance of 2 m from the computer screen. They were equipped with a special keyboard for the right hand, containing only five keys (one for each finger). The keyboard featured switches provided a loud and tactile click. The distance between keys corresponded to a comfortable distance between fingers of a relaxed hand. Participant were instructed about tasks and actions they needed to perform during the experiment.

One experimental session was consisted of 18 trials. During one trial, 30 visual stimuli were randomly demonstrated to the participant. Each stimulus was displayed on the screen for the time randomly selected by the program from range 1-1.5 s. Abstract noisy images were demonstrated between stimuli for 3-5 s.

Every trial was accompanied by single-pulse or sham TMS delivered to one of six areas of the cerebral cortex: premotor, primary motor or somatosensory cortex of the right or left hemisphere. Through the experiment every area was stimulated 30 times with real TMS in 200 ms, 30 times in 800 ms and 30 times with sham. We have chosen these time points, since the delay in responding to a visual stimulus in humans is usually between 190 and 210 ms [12]. Our pilot study showed that 95% of RTs without TMS were above 800 ms. Presentation of visual stimuli and TMS were synchronized by the software that randomized the time intervals of stimulation in order to avoid subject's adaptation.

D. Stimulation protocol

Preparation for TMS began with the calibration procedure, which was carried out using the navigation system (Localite, Germany). Then we marked six stimulation areas on generated 3D model of participant's brain in navigation program.

For each participant we determined individual motor threshold (MT) as a minimum stimulation power that causes a motor response in 5 out of 10 stimuli [13]. This was necessary for calculation of the individual stimulation power: it was set on 90% of MT power.

TMS was delivered in two forms: as single-pulse real stimulation and as sham stimulation. Sham was performed according to the following principle: the stimulator coil was rotated 90 degrees relative to the surface of the head in order to create the effect of presence, but without sending impulses directly to the cortex.

For single-pulse stimulation, we used TMS Neuro-MS (Neurosoft, Russia) with flat figure-of-eight coil (100 mm). The coil was positioned and fixated above the stimulation area, and the handle was angled 45^{o} to the longitudinal cerebral fissure.

E. Statistical analysis

In this experiment, we received 24 unique conditions when stimulation delivered to subjects while they were solving a sensorimotor integration task. We estimated how their RT changes under different parameters of TMS in different cortical regions and in which cases the greatest number of mistakes were made. All calculations were performed in JASP.

We averaged RT for each participant under each unique condition to test if the RT changes between the different zones, side, time and type of stimulation. For this purpose, we used the repeated measures ANOVA. In order to determine significant main effect we performed a post hoc analysis depending on sample normality, which was verified using Shapiro–Wilk test.

To determine how TMS affects sensorimotor task accomplishment, we counted the number of incorrect answers for each subject in each unique condition. Then we used repeated measures ANOVA with post hoc analysis to find significant effects.

III. Results

We found that the combination of factors "zone" and "type of stimulation" had the main effect on the change in RT ($p=0.002$). With post hoc analysis we revealed significant differences only for the sensorimotor cortex when comparing sham and real stimulation ($p=0.040$). In this case, RT decreased while when sham stimulation delivered in sensorimotor cortex (Fig.2).

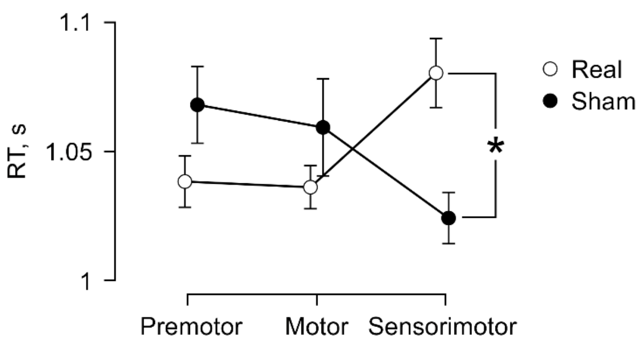

Fig.2. RT difference between zones depending on type of stimulation. Dots show group mean, error bars show standard error. The symbol * indicates statistical significance in post hoc analysis (* – $p<0.05$).

In addition, when taking into account stimulation time factor, post hoc analysis showed that significant differences in RT are also present in the sensorimotor cortex with sham stimulation at 200 ms and real stimulation at 800 ms (p=0.024).

Moreover, statistical analysis revealed some tendencies to decrease in p-value for the factors "side" (p=0.046), "time of stimulation" (p=0.085) and the combination of factors "type of stimulation * time of stimulation" (p= 0.059). We assume that this result was influenced by the small sample size (n=17) and an increase in the sample will help to reveal significant main effects in these cases.

As for the mistakes made in the process of completing the task under different conditions, we found several significant effects. Firstly, the number of mistakes strongly depends on the type of stimulation (p<0.001). With real stimulation, subjects made more mistakes than with sham stimulation. Secondly, post hoc analysis showed that this is especially true for the left motor (p<0.001) and sensorimotor cortex (p=0.011).

IV. Conclusions

At this stage of our work, we found that single-pulse TMS delivered to the sensorimotor cortex resulted in an increase of response time in the sensorimotor integration task. We suppose that the stimulation during the transmission of information along the association fibers to the motor cortex caused interference in the motor response and disrupted the process of sensorimotor integration. In addition, we found that real stimulation led to more mistakes made by subjects in sensorimotor task than sham stimulation.

The results we obtained at this stage suggest that TMS can be successfully used as a tool for the functional mapping of the cerebral cortex, including the process of sensorimotor integration. With further samples increase, we assume that it is possible to detect less pronounced effects of single-pulse TMS on sensorimotor integration process.

We believe that our results can be further used in researches and development of motor imagery based BCIs with neurofeedback (such as [14-16]) and machine-learning researches for BCI training (such as [17]) since sensorimotor integration is the core process for movement control.

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