Anterior TMS Speeds up Responses in Perceptual Decision-making Task

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***Abstract*— Our preliminary behavioral experiments suggest that the response time decreases when subjects respond to the repeatedly presented visual stimuli. A potential explanation is that the brain preactivates neural ensembles responsible for stimulus processing. If so, activating these areas before the experiment may reduce the response time immediately, opening ways for exciting practical applications. To test this opportunity, we apply transcranial magnetic stimulation (TMS) before the subjects start performing a perceptual decision-making task. Having compared the response time between the TMS and control groups, we observed a significant change confirming our hypothesis.**

Keywords—response time, TMS, visual stimuli.

I. Introduction

Several studies report that observers respond faster if the same or similar stimulus is presented repeatedly with a brief interval. This may be the behavioral manifestation of neural adaptation, an activation of the stimulus-related neural circuits during their repeated engagement [1-5]. Based on these findings, we suppose that activating these circuits via electrical or magnetic stimulation will facilitate responses in the ongoing visual task. To test this hypothesis, we considered visual stimuli classification task and applied transcranial magnetic stimulation before the task begins. To define the target zone for stimulation, we analyzed EEG signals and find

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the channels' cluster where the signal power grows with the time on task. When stimulating this zone, the subjects reduced their response time compared to the control group that undergo SHAM (placebo) stimulation.

II. Methods

A. Participants

Thirty naive subjects (16 females, aged 18–33 years) with no previous psychiatric/neurological history and normal/corrected-to-normal visual acuity participated in the experiments after providing written informed consent. Experiments were approved by the local ethics committee of the Lobachevsky State University of Nizhny Novgorod and followed the Declaration of Helsinki.

B. EEG registration

We registered electroencephalograms (EEG) using a 48-channel NVX-52 amplifier (MKS, Zelenograd, Russia). EEG signals were recorded from 32 standard Ag/AgCl electrodes. The earlobe electrodes were used as a reference. The ground electrode was placed on the forehead. Impedance was kept below 10 KΩ. EEG was digitized with a sampling rate of 1000 Hz.

C. Visual stimulus and task

Visual stimulus was an ambiguous Necker cube. We introduced control parameter *a*, determining its ambiguity and orientation by adjusting the brightness of inner edges. The limit cases of $a = 0$ and $a = 1$ corresponded to the unambiguous projections of the left- and right-oriented cubes, whereas $a = 0.5$ determined a completely ambiguous image. The unambiguous projections were easily interpreted by an observer, while the interpretation of high-ambiguous images required more effort. We instructed participants to press either left or right key when recognizing left or right projection. For each stimulus, we estimated a behavioral response by measuring the response time, RT, which corresponded to the time passed from the stimulus presentation to button pressing [4,7].

D. Experiment

All participants took part in two experiments with 2-3 months break between them.

Experiment 1: participants were comfortably seated in a chair with both hands, they held a two-button input device connected to the amplifier. At the beginning and at the end of the experiment, we recorded resting-state EEG activity for 3 min. The Necker cube images of 25.6 cm were displayed on a 27-inch LCD screen (with the 1920×1080 pixels resolution; 60 Hz refresh rate) located at a distance of 2 meters from the participant. Each cube appeared on the screen for a short time interval, randomly chosen from the range 1-1.5 s. Between the stimuli, we demonstrated an abstract image for 3-5 s. The timing of Necker cubes presentations and the EEG streams were synchronized using a photodiode connected to the amplifier. During experimental sessions, the cubes with predefined ambiguity were randomly demonstrated 400 times, each cube with a particular ambiguity was presented about 50 times. Participants were instructed to press either the left or right key when recognizing the left or the right stimulus orientation. The experiment lasted around 45 min.

Experiment 2: we divided participants in two equal groups (TMS and SHAM). As the group names state, we applied transcranial magnetic stimulation to the first group, and the SHAM stimulation to the second group. After the stimulation, both groups followed the same protocol as in the experiment 1.

E. Stimulation

Stimulation started with the calibration procedure. We used the TMS navigator's system (Localite, Germany) to generate the 3D image of the participant's brain and mark the target zone on it. The activation zone was defined using EEG data recorded during experiment 1.

To find the individual motor threshold, we performed a set of 10 stimulations of the motor cortex with different power. The power at which evoked motor potentials arose in 5/10 stimulations was taken as an individual motor threshold. Further simulations were set on 120% of individual motor threshold power [8].

For stimulation we used TMS Neuro-MS/D Advanced Therapeutic (Neurosoft, Russia) with AFEC-02- 100-C cooled angulated figure-of-eight coil (100 mm). To navigate the coil, we used an infrared marker set to the target zone. The coil was placed and fixated over the activation zone, and the handle was angled 45º to the longitudinal cerebral fissure. We applied excitatory stimulation with such parameters: 1800 stimuli, 10 Hz, 3 minutes. For SHAM stimulation, all parameters were the same, but the coil was placed on its wing (90º relative to the head) to stimulate away from the head.

F. Statistical analysis

In the experiment 1, we tested how the RT changed with the time on task. We divided whole experiment in four intervals. Each interval contained 100 stimuli and lasted 11 minutes [4]. We contrasted mean RT on these intervals using repeated measures ANOVA with 1–4 intervals, ambiguity (HA and LA), and orientation (Left and Right) as within-subject factors. For significant main effects, we performed a post hoc analysis using parametric or nonparametric tests, depending on sample normality, which was determined using the Shapiro–Wilk test. Statistical analysis was performed in IBM SPSS Statistics.

Statistical analyses of brain activity were carried out based on the subject-level wavelet power, averaged over intervals 1-4. Contrasts between the four intervals were tested for statistical significance using a permutation test combined with the cluster-based corrections for multiple comparisons. Specifically, the F-tests compared four wavelet power sets for all pairs (channel, frequency). Items that passed the threshold corresponding to a p-value of 0.001 (one-tailed) were labeled along with their adjacent items and collected in separate negative and positive clusters. The minimum required number of neighbors was set to 2. The F-values in each cluster were summarized and corrected. The maximum amount was entered into the permutation structure as a test statistic. A cluster was considered significant if its p-value was below 0.01. The number of permutations was 2000. All described operations were performed in MATLAB using the Fieldtrip toolbox.

Finally, we compared the median RT between the experiments 1 and 2 in the TMS and SHAM groups. We used paired samples t-test and Bayesian statistics. These calculations were made in JASP.

III. RESULTS

In experiment 1, we revealed a significant main effect of the interval on the RT ($p<0.0001$). The post hoc tests showed that RT on interval 1 exceeded the RT on interval 2 ($p<0.0001$), and RT on interval 2 exceeded RT on interval 3 ($p=0.0004$). Finally, RT on interval 3 was equal to the RT on interval 4 ($p=0.149$). We concluded that RT decreased with the time on task.

Contrasting ERSP between the intervals, we also found significant change. The post hoc test revealed that anterior ERSP grew with the time on task.

Using correlation analysis, we found that growing anterior ERSP negatively correlated with the decreased response time. Thus, we concluded that activation of the anterior zone during the experiment may facilitate sensory processing.

In the TMS group, the mean RT difference between two experiments was -0.0524 s [95%CI -0.0848, -0.00473], p= 0.023. The Bayes factor for alternative hypothesis ($RT_{experiment1}>RT_{experiment2}$) was 5.55 suggesting the strong evidence.

In the SHAM group, the mean RT difference between two experiments was -0.006 s [95%CI - 0.0641, 0.0431], p=0.844. The Bayes factor for alternative hypothesis ($RT_{experiment1}>RT_{experiment2}$) was 0.37, there was no data supporting an alternative hypothesis.

IV. CONCLUSION

We found that during a visual task with the repeated presentation of similar stimuli, subjects reduced their response time and demonstrated growing EEG power at the anterior electrodes. Stimulating this area via TMS resulted in the reduction of the response time.

Thus, we confirmed the engagement of this zone in the perceptual process and made the first step in designing the stimulation protocols for enhancing brain ability to process sensory information.

Our results may find applications in brain-computer interfaces with biological feedback to control and enhance human attention [9,10].

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