The effects of transcranial direct current stimulation (tDCS) on cognitive control in healthy participant

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Abstract

In this work we tested the effects of non-invasive transcranial direct current stimulation (tDCS) on cognitive control abilities in adult subjects. Cognitive control is defined as the ability to select a thought or behavior according to a specific goal (Blasi et al., 2006), encompassing a wide range of mental activities, such as goal representation, attention focusing and stimulus-response mapping (Carter et al., 1998; Cohen et al., 1990; Miyake & Shah, 1999; Shallice, 1988). Cognitive control represents a set of functions at the base of the cognitive system, which are active while carrying out various cognitive tasks, and when response is required to unusual situations (Botvinick, Cohen & Carter, 2004). Cognitive inhibition is a derivative of cognitive control, which allows the brain to select which representations will receive attention, and which will be ignored. tDCS is a painless device, whereby a weak electrical current is passed through the scalp, between a positively charged electrode and a negatively charged electrode (anodal and cathodal, respectively).

This device is capable of generating a focused change in the brain's neurological sensitivity, which can be either an increase or a decrease, according to the electrode's polarity (Fregni et al., 2005). In this study, we aim to test the effects of tDCS on the dorsal lateral prefrontal cortex (DLPFC), with respect to cognitive control, through the use of several tasks. The DLPFC has a guiding role, whereby it directs working memory processes, and guides other brain regions to perform memory preservation, representing top-down control. In addition, this area has been shown to monitor and filter information for the purpose of deciding on carrying out an adapted response (D'Esposito & Postle, 2015; Ester, Sprague & Serences, 2015; Geier, Garver & Luna, 2007; Miller & Cohen, 2001; Sreenivasan et al, 2014a). This work includes three main experiments. The first assessed the impact of tDCS stimulation on cognitive control abilities, requiring identification and filtering of irrelevant cognitive information during exposure to a series of sentences. The effect of stimulation was examined in both the short term and the long term (one month following the last stimulation). The second experiment tested the effect of tDCS stimulation on cognitive control abilities required in verbal and visuospatial working memory tests. Lastly, the third experiment evaluated the effects of tDCS stimulation on cognitive control abilities under different levels of cognitive load, in the n-back task, in both the short- and long term. All experiments were approved by the institutional Bar-Ilan ethics committee, and all subject provided an informed consent in writing by signing informed consent forms.

The first experiment examined the effects of bilateral DLPFC stimulation on the ability to suppress irrelevant information while being exposed to a set of stimuli via the Hayling test. The anodal electrode was placed on the left DLPFC region (F3), and the cathodal electrode was

placed on the right DLPFC region (F4). During this test, which is composed of two parts, subjects are required to complete the last word of a sentence. In the first part, the subject is presented with a sentence using earphones and is asked to complete the sentence by saying a word that is logically connected to the sentence he just heard. For instance, when the sentence "I usually eat with a knife and a…" is played in the earphones, most subjects will say "fork". In the second part of the test, which assesses higher executive functions such as verbal suppression and planning, the subject is asked to say a word that is logically unrelated to the sentence presented in the earphones. For instance, saying the word "pants" following the sentence "I usually eat with a knife and…".

The experiment included 20 subjects, aged 21-41 years, which were divided into a study group (n=12) and a sham group (n=8). The experiment was double blinded, and included seven sessions. In the first session, the subject carried out phonemic and semantic verbal fluency tests, after which they immediately performed the Hayling test. The test included the completion and suppression parts, and was used as a baseline test for assessing the extent of change in electrical stimulation. Following the baseline test (T1), the first stimulation was carried out. Each subject completed a total of 6 stimulations of 2 mA, each lasting 20 minutes, in the course of 2 weeks (3 stimulations per week). At the end of the sixth and last stimulation, the subjects again performed the two part Hayling test (T2). In addition, one month following the last stimulation, the two parts of the Hayling test were again carried out (T3). The Sham group underwent an identical procedure, except that actual stimulation was given for only 30 seconds at the beginning and 30 seconds at the end of the stimulation. We were able to confirm our hypothesis, as the experiment demonstrated a lower error rate following DLPFC stimulation in the study group, compared to the sham group. The improvement was already seen immediately following the last stimulation and was even more significant one month following the last stimulation. Nonetheless, we were unable to detect changes in response times between the different measurements in the study group, compared to the sham group.

These results indicate the bilateral DLPFC stimulation can improve cognitive control abilities, including suppression of irrelevant information, in both the short- and long term. This holds important practical implications, in light of the tDCS ease of use and long term effect, as well as the difficulties in cognitive control, frequently seen in various clinical populations, negatively affecting the daily lives of patients.

The second experiment was composed of two parts. In this experiment, we were interested in examining the effects of bilateral DLPFC stimulation (left-anodal, right-cathodal) on cognitive control abilities using verbal working memory test Letter-Number Span (LNS) and visuospatial working memory test Brief Visuospatial Memory Test—Revised (BVMT–R). During the LNS test, the subject is asked to listen to a list of letters and numbers. Next, he is asked to repeat this list by saying the numbers he had heard, in an ascending order (1-9), and then the letters in an alphabetical order, without any time limit. In BMVT-R test, the subject is asked to memorize the structure of six geometrical shapes in a matrix of 2X3 presented on an A4 page. The subject is then requested to reconstruct and draw each of the shapes on an empty A4 page, in the most precise way possible, with respect to both the geometrical structure and position relative to the other shapes. This test was performed in two versions, one as a baseline test, and the second as a post-stimulation test. The experiment, carried out in one session, included 24 subjects, aged 20-33 years, which were randomly assigned to the test (n=12) or control (n=12) groups. The subjects completed phonemic and semantic verbal fluency tests, after which the baseline (T1) LNS and BMVT-R tests were performed. Then, bilateral DLPFC stimulation using 2mA for 20 minutes was carried out. At the end of the stimulation, the subjects carried out the LNS and BMVT tests again (T2), in a double blind manner, such that half carried out the LNS test first, and half carried out the BMVT-R first. The experiment confirmed the study hypothesis, demonstrating an improvement in the experimental group compared to the control group, in the scores of the LNS and BMVT-R tests following stimulation (T2), compared to the baseline test (T1).

These results indicate that DLPFC stimulation can modulate cognitive control in visuospatial working memory tasks.

The third experiment tested the effects of bilateral DLPFC stimulation (left-anodal and right-cathodal) on cognitive control abilities under 4 levels of cognitive load, using the short- and long term n-back shape test. In this experiment we calculated the percentage of correct answers, percentage of false alarms, and reaction time for correct answers. The experiment, which was carried out in 7 session, included 25 subjects in the ages of 20-41 years, who were divided into control (n=9) and experimental (n=16) groups. During the first session, the subjects carried out the phonemic and semantic verbal fluency tests, after which they immediately performed the n-back test, serving as a baseline (T1). Then, the first stimulation was carried out. Each subject completed a total of 6 stimulation of 2mA for 20 minutes in the course of 2 weeks (3 stimulations per week), in a double blinded manner. At the end of the sixth and last stimulation, the subjects were asked to carry out the n-back test again (T2). In addition, one month following the last stimulation, the n-back test was performed for the third time (T3). The results did not support our hypothesis. Even after performing separate statistical analysis for each level of cognitive load, we did not detect a significant result, but only a decrease in response time for n=1 in the experimental as compared to the control group in the long-term. However, the results did not indicate an improvement resulting from the stimulation, and therefore additional studies are required in order to determine the efficacy of tDCS-induced stimulation in various cognitive control tasks.

In conclusion, our results indicate an improvement in short- and long-term cognitive control, including suppression of irrelevant information, whereby the subject is required to suppress arising matching words and look for a semantically incompatible word. Furthermore, we demonstrate an improvement in cognitive control encompassing preservation of verbal and visuospatial information, as well as manipulating verbal information. In contrast, we were unable to prove the hypotheses of the third experiment, examining the effects on carrying out a working memory cognitive control test, the n-back shapes. Thus, the results of this study require further confirmation.

This work will serve as further validation to the effects of serial, as well as single, stimulation on cognitive control, in tasks of working memory, and especially in suppressing irrelevant information. Moreover, our results refer to bilateral stimulation, which has been rarely used in healthy subjects. Hence, they could contribute to the discussion surrounding the type of optimal montage required to obtain improvement following stimulation.

Importantly, our findings surrounding long term effects of stimulation pave the way towards future studies, which could involve a relatively simple and non-invasive technique, as a means to improve the quality of life of clinical populations, directly affected by deficits in these functions. Specific examples of such populations include schizophrenia patients, as well as the adults within the autistic spectrum.