The Effect of Transcranial Direct Current Stimulation on Working Memory in College Students of Delhi NCR

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ABSTRACT:

Background: Transcranial stimulation with weak direct current (DC) have impact on cortical regulation of different neural systems.Working memory refers to the temporary storage and manipulation of the information necessary for complex tasks such as language comprehension, learning and reasoning.

Objective: To examine the impact of transcranial direct current stimulation on working memory.

Method: Total of 45 subjects were recruited for the present study. Participants were randomly assigned into three groups: anodal (n= 15), cathodal (n=15), sham (n=15). A constant current of 1 mA intensity was applied for 10 min on each participant. For sham stimulation, the electrodes were placed in the same position; however, the stimulator was turned off after 30s. Participants were made to run a Sternberg memory task before the stimulation and after the stimulation and their number of correct responses were noted using analysis of variance.

Result: Significant mean difference was present between anode and cathode groups (p= 0.0001) as well as between anode and sham groups (p= 0.002) when considering pre-test. In post-test post hoc analysis, significant mean difference was found between anode and cathode groups (p= 0.019) as well as between anode and sham (p= 0.004) while no statistically significant mean difference is found between the cathode and sham group.

Conclusion: The observed change at 1 mA over prefrontal excitabilityenhanced the working memory without any harmful effects. So it can be concluded that TDCS is an effective tool in enhancing working memory.

Keywords:Transcranial Direct Current Stimulation (TDCS), Anodal stimulation, Cathodal stimulation, Sham stimulation, Stern berg memory task, working memory.

INTRODUCTION

Working memory (WM) capacities are of unequivocal significance for effective human behavior. It is a developing yet overlooked psychological process that can be viewed as a crucial component of executive function.It is referred as the temporary storage and manipulation of the information necessary for complex tasks such as language comprehension, learning and reasoning[1] and plays an important role in long-term memory,language, and executive function[2].

The neuro transmitter,dopamine, plays a critical role in spatial working memory[3]. Dopamine (DA) concentration has found to be highest in the prefrontal cortex out of all cortical areas inprimates[4].Thefunctionalimportance ofDAinspatialworkingmemory hasbeen experimentally verified by previous research and depletion of DA in the prefrontal cortex or pharmacological blockade of DA receptors has been shown to impair spatial delayed-response tasks[5, 6].
Tran cranial Direct Current Stimulation (TDCS) with weak DC is important in the impact of cortical regulation on different neural systems. As it being an old technique for stimulating the brain, its behavioral effects on humans are not much known. The recent studies regarding the stimulation of the brain particularly transcranial magnetic stimulation (TMS), have placed the TDCS in the research agenda of brain stimulation. These studies have shown that this technique can be safely used in human beings[7].
TDCS includes the stream of direct current through two sponge electrodes to the scalp. The gadget utilized in transcranial direct current stimulation is equipped to convey a steady electrical current flow of up to 2 mA. It consists of two electrodes absorbed in water and is then kept inside sponges (20– 35 cm2); that are held by a non-conducting rubber montage i.e. attached around the head. TDCS effects are transferred by polarizing the brain tissue. The anodal stimulation, for the most part, expands sensitivity helps in stimulating the area applied and the cathodal stimulation, by and large, lessens the sensitivity i.e. helps in inhibiting the area applied[15].

WM impairment is a major feature in a number of neurologic and psychiatric disorders, including schizophrenia, Alzheimer's disease, Parkinson's disease, and major depression. Despite this, no effective treatment has yet been established. Some studies have indicated that antipsychotics, particularly the newer atypical antipsychotics, may improve cognitive functioning in. However, results in this area have been inconsistent. Deficits in WM play a crucial role in psychiatric disorders particularly schizophrenia and dementia[18, 19].

Sternberg presented his ''memory scanning'' paradigm in the framework of memory retrieval. It consists of a sequence of digits defined as ''the positive set' which are drawn randomly from set of digits between 1 and 9. These digits are shown one by one and participants are instructed to memorize them. Whereas, the digits which are not shown to the participants constitute the ''negative set''. After a signal, a test digit is presented and the subject has to decide as quickly and accurately as possible whether or not the test digit had occurred in the memory set.Past literature has shown different results regarding anodal and cathodal stimulation. Some studies have found significant relationship between anodal and cathodal stimulation.[8, 11, 20, 23, 24, 25]It was observed that the anodal TDCS of the right DLPFC led to an increase of tolerance to heat pain and it suggests the involvement of the DLPFC in the processing of pain and WM. The study by Thomas E. Gladwin, Tess E. den Uyl, et. al. (2012)[27] showed that the TDCS was found to improve reaction time significantly only when the incorrect choice had been a distracter stimulus while M. A. Nitsche and W. Paulus (2000)[26] showed a significant effect of the polarity of current stimulation and a significant interaction of polarity and time course.

Whereas, some studies have shown negative relation between anodal and cathodal stimulation. Carvalho S, Paulo S. Boggioet. al. (2015)[28] observed that two consecutive sessions of anodal TDCS delivered with a 10 min interval between them did not improve WM performance and the effect remained the same if the interval was increased to 30 or 60 min. In contrast, when a 10 min interval was given between two consecutive cathodal TDCS sessions, performance in the 3 back tasks increased. Since there exist a discrepancy in the present literature regarding the association between anodal, cathodal and sham, thus through empirical testing this study tries to clarify and understand the relationship between anodal, cathodal and sham stimulation in order to provide useful insights for future research.

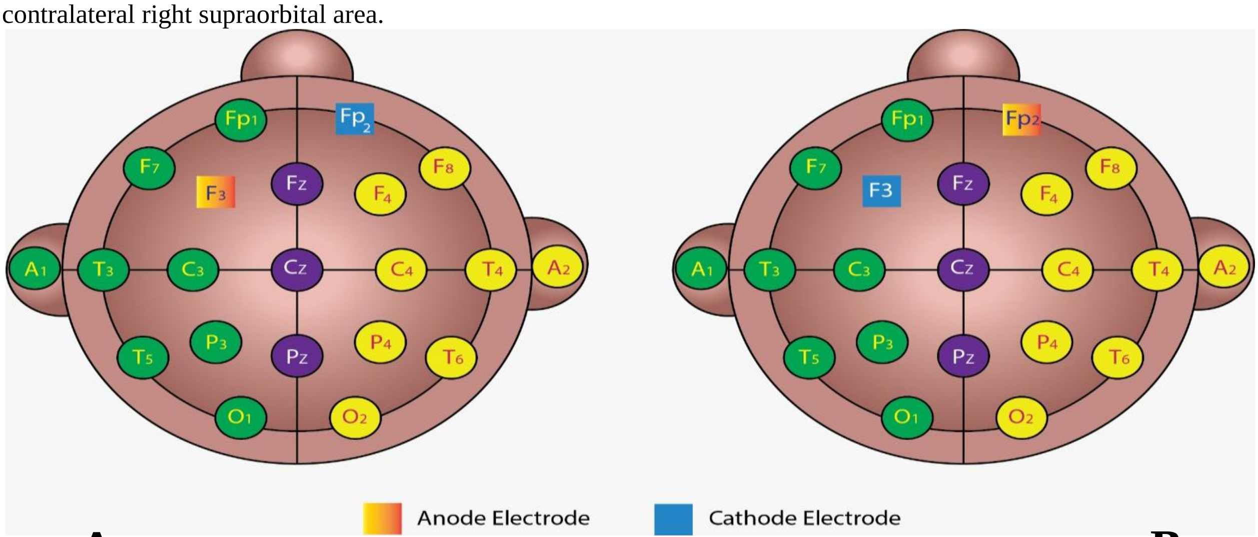
METHODOLOGY

The study was approved by the Research development committee of School of Physiotherapy, DPSRU University New Delhi. A sample of convenience of 45 healthy young adultsof age from 19–22[1] years (mean 20.2± 2 years) who met inclusion and exclusion criteria and were willing to participate were selected from Delhi Pharmaceutical Sciences and Research University, New Delhi-110017. The study was conducted in the month of December 2018-Feburary 2019. Ethical approval was granted by Research development committee of School of Physiotherapy, DPSRU University, and registration number: 10/715/Registrar/office/DPSRU/2018/9947.

Subjects of age group: 19- 22 years, non-smokers were included in this study. Participants with history of vertebra-basilar insufficiency, seizure disorder, epilepsy, pregnant ladies, cognitive impairments, metabolic or circulatory disorders. A battery-driven, constant current stimulator delivered the direct current which was transferred via saline-soaked pair of surface sponge electrodes (35 cm^2) with a maximum output of 10 mA. The subject was seated comfortably on the chair. To stimulate thedorsolateral prefrontal cortex(DLPFC), the electrode was placed according to the 10–20 international system for electroencephalogram (EEG) electrode placement. A constant current of 1 mA intensity was applied for 10 min. Subjects felt the current as an itching sensation at both electrodes at the beginning of the stimulation. For sham stimulation, the electrodes were placed in the same position; however, the stimulator was turned off after 10s. Therefore, the subjects felt the initial itching sensation in the beginning but received no current for the rest of the stimulation period.

The montage of the electrodes for different conditions was as follows:

1. For anodal and sham stimulation of the left DLPFC, the anode electrode was placed over F3[8, 9] (according to the 10-20 international system for electroencephalogram electrode placement), and the cathode electrode was placed over the contralateral right supraorbital area.
2. For cathodal stimulation, the cathode electrode was placed over F3 and the anode electrode was placed over the contralateral right supraorbital area.



A B

Working Memory Assessment

The participants were seated comfortably at about 60 cm from the computer screen. First, the experimental task instructions were displayed on the screen. The experimenter allowed the participant enough time to read the instructions carefully. When the subject had finished reading the instructions, the experimenter went over the important points to make sure he/she understood the task. The items in the sequence were presented one by one in the middle of the screen for 1.2 s each. Sequence length varied randomly across trials. Participants had to decide as quickly and as accurately as possible whether this digit was in the sequence just presented. The sequence of digits presented one at a time printed in white, immediately following each sequence a final digit appeared in yellow. The task of the subject was to decide whether or not the yellow digit appeared in the preceding sequence. If the yellow digit appeared in the sequence, press the left ("F") key. If the yellow digit was NOT in the sequence, press the right ("J") key. For every correct answer, a Green "O" appeared and for every incorrect answer, a red X appeared. To answer, they had to use their dominant hand to press a key on the standard keyboard if they thought the test digit was in the sequence, and another key with their other hand if not. As soon as one of the keys was pressed, a one-word feedback message about the answer (''correct'' or ''incorrect'') appeared on the screen to encourage participants to respond quickly while keeping their error rate as low as possible. The test block consisted of the 18 trials in which set size was randomly selected.

TDCS and Sternberg Memory Task

Experimental Group Protocol

The subjects were asked to be seated comfortably on the chair. Informed consent was taken and all instructions were made clear to the subjects. Subjects were asked to perform Sternberg Memory Task and the scoring at the end of the assessment was noted. TDCS was applied for 10 minutes. Subjects were asked to rest for 5 minutes and if they felt any side effects such as redness over the site of application and itching was noted. Again the subjects were asked to perform the Sternberg Memory Task and the results obtained were noted.

Control Group Protocol:

The participants were made to sit comfortably on the chair and the subject were asked to perform Sternberg Memory Task, the scoring of the test were noted. TDCS was applied with the electrode at the same position as for the anodal stimulation, however the stimulator was turned off after 10 seconds. In all, the subject felt itching at the beginning of the stimulation but no sensation was felt for the subsequent time.

RESULT

The outcome for the study was number of correct responses, incorrect responses (errors) and during active compared to sham stimulation. The data were analyzed using statistical tests, using SPSS 11.5 software packages.ANOVA Test has been performed for comparing working memory with Sternberg memory task within and between the groups i.e. A, B & C.Significance level (p) has been selected as 0.05.

As shown in Table 1; among the stimulation, in the pre-test cathode has the highest mean score (0.9146), followed by sham mean score (0.8815) and anode mean score (0.748). In the post- test sham has highest mean score (0.9481), followed by cathode mean score (0.9222) and anode mean score (0.8230).

Table 1 shows that there is a statistically significant difference between groups as demonstrated by one-way ANOVA for pre-test ($F = 9.048$, $p = 0.01$) and post-test($F = 5.322$ $p = 0.09$) .

Table 1 ANOVA between the Group Memory

	Mean ± SD			**F Value**	**P Value**
	Anode	**Cathode**	**Sham**		
PRE TEST	0.7481± 0.15835	0.9146 ± 0.08088	0.8815±0.08364	9.048	0.01
POST TEST	0.8230±0.14466	0.9222±0.11071	0.9481±0.06110	5.322	0.09

ANOVA between the group tests revealed that in the anodal TDCS with Sternberg memory task condition, participants' accuracy improved significantly after stimulation. There were no significant differences between performances pre- and post TDCS in the sham with Sternberg memory condition, or in the active TDCS.

The post hoc test is reported in table 2 wherein results shows thatthere is significant mean difference between anode and cathode groups (p= 0.0001) as well as between anode and sham groups (p= 0.002) while considering pre-test. However, there is no statistically significant mean difference between the cathode and sham ($p = 0.429$). When considering post-test post hoc analysis, significant mean difference is found between anode and cathode groups (p= 0.019) as well as between anode and sham (p= 0.004) while no statistically significant mean difference is found between the cathode and sham ($p = 0.0526$).

Table 2 Post Hoc Analysis between the stimulations of Mean

		P Value	Inference
PRE TEST	Anode vs Cathode	0.0001*	Significant
	Cathode vs Sham	0.429	Insignificant
	Anode vs Sham	0.002*	Significant
POST TEST	Anode vs Cathode	0.019*	Significant
	Cathode vs Sham	0.0526	Insignificant
	Anode vs Sham	0.004*	Significant

*significant at 5% level

DISCUSSION

The primary purpose of this study was to detect the effect of TDCS on working memory. The outcomes showed that WM performance was commonly improved from the sham to the active stimulation, which demonstrated a repetition- related learning impact on WM task execution. In particular, this improvement in WM performance was impacted by active TDCS in a polarity-specific way.

The research study showed that the effect of the stimulation of the left DLPFC depends on the polarity of stimulation. The results have shown that the anodal stimulation results in the enhancement of the working memory.

The outcome of this study may be due to a brief episode of strong synaptic activation that leads to a persistent strengthening of synaptic transmission. The model of neural plasticity is said to underlie learning and memory in LTP. The present study is supported by a study done by Floel and Cohen who suggested that noninvasive cortical stimulation, in combination with memory training, may enhance the effects of training via LTP[22, 29].

These impacts were may be because of an improvement of the local cortical excitability of the left dorsolateral prefrontal cortex since (i) anodal TDCS induces a membrane effect in the neuron characterized by a neuron depolarization[10, 11]and therefore can expand local excitability as shown by the previous study in the human motor cortex[11, 12]; and (ii) the DLPFC is critical to working memory development as appeared past neuroimaging and rTMS studies[11, 13, 14].

Though anodal or the experimental group was found to be more significant than others but sham group i.e. the control group also showed a significant difference in working memory but less in comparison to the experimental group which may be because subjects were of enthusiastic about the procedure and were trained earlier before performing their main experiment, so they were more focused and gave or provided more concentration on the test during the procedure[16, 17].

Furthermore, this controlled experiment showed that the effect of the anodal stimulation of the left DLPFC was relatively focal and depended on the polarity of stimulation. This accuracy enhancement during active stimulation cannot be accounted for by slowed responses, as response times were not changed by stimulation. These results showed that left prefrontal anodal stimulation leads to an enhancement of working memory performance[20, 21].

Significantly, this improvement in WM execution was impacted by active TDCS in a polarity-specific manner. The improvement in WM execution was essentially more pronounced after the application of anodal than after cathodal TDCS over the left dorsolateral prefrontal cortex (DLPFC), while the WM improvement was intermediate when participants received no electrical incitement. Along these lines, anodal TDCS improved the regular repetition-related increase in WM performance, though cathodal TDCS interfered with this impact. Anodal TDCS expanded while cathodal TDCS diminished the memory performance.

The study could be used clinically for the application of stimulation could be extended to elite cognitive responses in neurological conditions and even can be used to enhance sports person performance. It is also valuable in the domain of relearning programs. Also it can be applied to extend the benefits of tDCS to therapeutically relevant tasks and durations.

The study has certain drawbacks wherein the sample size was small and is limited to particular age group only. Also, Placebo effect is present in the sham group which resulted in the significant results. Thus, generalization cannot be made.

There is scope for future research pertaining to current study. The study could not only result in enhancement of neurological related cognitive impairment but could also be used to enhance sports people's performance. It could also be used to detect the cognition, perception and reflex action of the neurological patient or could be used in normal subjects to increase them. Future studies should address the durability of this effect when repeated sessions of TDCS are administered. If replicated, such a finding could have important implications for the use of cognitive remediation and brain stimulation as adjunctive techniques to enhance WM across a number of neurologic and psychiatric conditions.

CONCLUSION

The present study investigated the impact of anodal, cathodal and sham TDCS over the left DLPFC. Our results show that anodal TDCS can change the organized cortical activity associated with WM in concert with systematic alterations of WM performance. The results of the study have provided a better understanding of the neuro-modulatory effects of anodal TDCS and demonstrate its potential both at increasing knowledge on the functional significance and for therapeutic application.

We can conclude that a change in the prefrontal excitability by 1 mA can change working memory performance without adverse effects and results in a behavioral improvement. The results of this study underscore the importance of cortical excitability and activity enhancements for working memory function. So it can be concluded that TDCS is an effective tool in enhancing working memory.

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