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Impulsivity and Reward Choice: Role of Non-Invasive Brain Stimulation

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In intertemporal choice (ITC), people discount future rewards in proportion to the time delay until reward is received. Imaging studies showed frontal cortex activation during delay discounting task (Ballard & Knutson, 2009). A repetitive low frequency TMS in the left DLPFC showed increased choices of immediate rewards over larger delayed gains, compared to the sham stimulation (Figner et. al., 2010). Given the extensive involvement of prefrontal region in intertemporal choices, this study aimed to investigate whether modulating prefrontal activity with tDCS has any effect on reward choice in delay discounting tasks. 30 healthy participants (mean age: 22.5 years) participated in this study. On each experimental day active tDCS and sham tDCS (separated by at least one week) was applied on each participant when performing delay discounting task to identify indifference point (Mazur, 1987; Green & Myerson, 2004). The results show that independent-samples t-test was conducted to compare delay discounting rate (K) for tDCS and sham conditions. There was a significant difference in the scores for tDCS (M= .026, SD= .01) and sham (M= .073, SD= .06) conditions; t (29) = 2.137, p= 0.04 which indicate that the anodal stimulation over left DLPFC decrease temporal delay discounting. Participants preferred more choices of larger delay reward, instead of smaller immediate option, when the left DLPFC was stimulated compared to the sham stimulation. These observations indicate the significant role of the left prefrontal cortex in intertemporal choice and demonstrate that increased left DLPFC activation can alter decision making by intensifying a tendency to choose delayed gains. .

Keywords: Delay Discounting Choices, DLPFC, tDCS, TMS, sham stimulation, indifference point.

Rewards influence human behaviour; this is one of the basic teachings of behavioural psychology. Of the several factors modulating reward effect on behaviour, the timing of rewards has been of special interest to psychologists. One question that has puzzled behaviourists for centuries is why human beings prefer smaller, immediate and disastrous rewards even when the alternative of larger, later and advantageous are available. The choice preference for smaller immediate rewards can be termed as 'impulsiveness' while for later larger rewards as 'self-control'. The issue of impulsiveness is as old as civilization as its first roots are evident in the Garden of Eden created by God. Research literature outlines impulsiveness to be the result of poor knowledge of consequences, compulsion or flawed valuation of consequences (Ainslie G., 1975). People prefer smaller immediate rewards as they are available now and with lesser effort than the larger, later ones for which considerable wait time and efforts are required.

Delay discounting and impulsiveness

One factor that influences the maladaptive behaviour of impulsiveness is delay discounting: the cognitive process used by individuals to evaluate the remote consumption of a commodity as of less value than its immediate consumption. Delay discounting is considered as an index of impulsive behaviour. Delay discounting evaluates the relationship between decrease in subjective value of trade goods and the delay in the delivery of the goods (Rachlin, Brown & Cross, 2000). Larger discounting would suggest high levels of impulsivity caused by the delivery of goods (Daruna & Barnes, 1993; Oas, 1985; Reynolds & Schiffbauer, 2005; Richards et al., 1999). Delay discounting can be thought of as the depreciation of value of a

reward as a function of time of release of the reward (Tesch & Sanfey, 2008), or depreciation in subjective value of consequences (Backer, Johnson, & Bickel, 2003). Delay discounting can be compared with traits that vary in relation to changing environmental conditions (Dallery & Raiff, 2007). The delay discounting process assumes that after a choice is made immediate and delayed subjective values are assigned automatically that can increase or decrease depending on nature of choice, what and how much is chosen and whether the situation is of advantage or loss (Tesch & Sanfey, 2008). Delay discounting process are dependent on several suppositions. One supposition believes that the delayed release of a commodity decreases its subjective value and its preference drops. In addition, if future events are heavily discounted, they will have less impact on current behaviour leading to an impulsive choice (Backer et al., 2003; Odum et al., 2000). Studies on delay discounting point out the ways in which the decision factors like risk and time hamper with everyday decisions like financial investments for secure future. Long-term high reward depends on one's ability and motivation to wait for future rewards over immediate gratification with lower rewards. Waiting for a larger reward in future requires mental efforts that vary with the size of the proposed rewards (Thaler, 1981). Large future rewards are generally associated with positive outcomes including better academic performance and healthy social relationships (Hirsh, Morisano & Peterson, 2008) and lower incidences of psychopathology and criminal behaviour (Shamosh & Gray, 2008). These benefits only matter if the future is relatively predictable (Hirsh et al., 2008). Human delay discounting studies estimate discounting indexes by testing people under hypothetical or real situation and systematically varying reinforcement values and delay of reinforcements (Robles & Vargas, 2008). Participants in delay discounting studies make choices between immediate smaller over delayed larger rewards. The delay periods of discounting are varied which yield a lot of constant information (Green, Fry, & Myerson,1994; Richards, Zhang, Mitchell, & Wit, 1999). Participants are given a series of queries with choices between smaller, immediate and larger, delayed monetary gains and they must answer them. The smallest immediate reward value that participants choose over delayed value is termed as the indifference point, at which the subjective value of immediate and delayed rewards equalizes. The obtained indifference point can be plotted as a discount function that take the form of a hyperbolic function (Mazur, 1987), which is represented below:

$$V = A / (1 + kD), \qquad (1)$$

Here, V is the delayed reinforce, A is the value of reinforce and D, the delay respectively. The steepness of the discounting curve can be represented in terms of the K values that are directly proportional with the rate of discounting and impulsiveness (Mazur, 1987; Richards, Zhang, Mitchell, & Wit, 1999).

Non-Invasive stimulation and impulsiveness

Neuroimaging and brain lesion studies have identified elementary cognitive functions and neural substrates of impulsiveness (Pattij & Vanderschuren, 2008). The pre-frontal cortex (PFC) is one substrate that performs cognitive control that predicts goal attainment. The PFC modulates functions involving inhibitory control, planning, delay discounting, attention (Aron, Robbins, & Poldrack, 2004; Gazzaley & Nobre, 2012). Hyperactivity of PFC leads to the deficits of the above functions that in turn promote large motor and cognitive impulsivity (Dalley. Everitt, & Robbins 2011). Non-Invasive brain stimulation (NIBS) modulates brain activity below the stimulation site and of remote brain sites through a network of neural connections. Transcranial direct current stimulation (tDCS) uses saline soaked electrodes to deliver the feeble current that modulates brain activities in associated sites. Anodal electrodes increase while cathodal electrodes decrease brain activity. Studies using NIBS on the PFC measured impulsivity using the delay-discounting task. Recently, Hecht, Walsh, & Lavidor (2013) conducted a bi-lateral tDCS study that evaluated the relationship between delay discounting choices and prefrontal cortex activation. They found that bi-lateral stimulation of the PFC could alter decision making on delay discounting tasks in terms of higher likelihood of choice for immediate gains

over delayed gains. Cho et al. (2015) however found that high frequency bilateral repeated Transcranial Magnetic Stimulation (rTMS) of the DLPFC, decreased impulsivity. Several other studies all involving TMS reported varied results of NIBS on impulsivity (Grall-Bronnec, & Sauvaget 2014). Evidence from imaging studies on the role of the frontal cortex in time discounting is only correlative. Brain stimulation techniques for studying time discounting are more advantageous than imaging studies as they allow us to infer casual conclusion.

In the present study, we used randomized, single-blind sham-controlled procedure to test whether direct current stimulation of the left dlPFC would modulate delay discounting in healthy adults. Our working hypothesis is that the stimulation of dlPFC should influence the rate of temporal discounting which in turn will influence the level of impulsivity. Our working hypothesis is based on previous research evidence that suggests that DLPFC neural activity shows positive correlation with subjective valuation of a delayed reward. We thus propose that the reduced impulsivity from the direct current stimulation of the DLPFC will make individuals prefer delayed larger rewards. In case, the direct current stimulation of the dlPFC leads to increase in impulsivity and the likelihood of choice for immediate small rewards will peak.

Method

Participants

Thirty undergraduate students (mean age = 22.6 ± 2.1) from Indian Institute of Technology, Guwahati volunteered in exchange for partial credit toward a course requirement. All subjects had normal or corrected-to-normal vision and did not report any psychiatric disorders. Participants completed the following set of questionnaires: a personal data form including questions about age, gender, eyesight, etc. along with informed consent form. The study was carried out at the Indian Institute of Technology, Guwahati. Ethical approval was obtained from the Institute of Human Ethics Committee (IHEC). All participants were provided written informed consent and were debriefed fully at the end of the experiment.

Design and procedure

This study employed a subject design that was run double blind. Participants underwent two stimulation sessions viz. active (direct current stimulation) and sham (control condition with no current) in random order. The order of stimulation was counterbalanced across participants. An intersession interval (≥48 h) ensured no carryover effects due to stimulation. Both stimulation sessions were conducted at approximately the same time of the day in order to minimize circadian effects.

Active transcranial direct current stimulation (tDCS)

Direct current stimulation using tDCS lasted for 20 minutes. NeuroConn DC-Stimulator (Ilmenau GmbH, Germany) delivered a constant 1.5mA current (10 second fade in/out) through two surface sponge electrodes (0.9% sodium chloride soaked) with 35 cm 2 surface area. Previous research suggests the at least 50% of the applied current will pass through the skull and enter the brain (Nitsche et al., 2008). Anodal stimulation was applied over the left dorsolateral prefrontal cortex (DLPFC) while the cathode lead was placed over right eye (Orbitofrontal cortex) for control. Standard 10-20 montage was used for DC stimulation. The tDCS parameters used in our study adhere to international standards of safety for healthy individuals (Iyer et al., 2005). The charge density was two magnitudes lower than the experimentally determined threshold estimate in rats (Liebetanz et al., 2009). tDCS is highly tolerable process with minimal side effects of mild tingling sensation reported by most tDCS volunteers (Poreisz, Boros, Antal, & Paulus., 2007).

Sham transcranial direct current stimulation (tDCS)

Sham (control) stimulation electrode placement was like that of the active direct current stimulation. During Sham stimulation, the participants experienced the 10 sec fade in/out with the active current being switched off to 30 seconds into the stimulation. Due to this participant experiences the initial itching sensation like active stimulation however, no current is delivered to the scalp electrodes for

the 20-minute session. Research shows that this method for sham tDCS is reliable and cannot be easily distinguished from the real tDCS by participants (Gandiga, Hummel, & Cohen, 2006).

Temporal Discounting (TD) task

The momentary delay-discounting task presented two choices to the subjects, with hypothetical delay rewards or an immediate reward (see Fig.1 (A)). Before choices were displayed on screen, instruction was read:

"I am going to ask you to make some decisions about which reward you prefer. You will not receive the rewards that you choose, but we want you to make your decisions as though you were really going to get the reward you choose. The possible options for rewards are displayed on the computer screen. The option on your left show a reward that you can get immediately and the option on your right show a reward that you can get after you have waited for some period. The choice you make are completely up to you. Please select the option that you prefer most by pressing the specific key ('z' for left and 'm' for right) on the keyboard."

The immediately available monetary rewards were decreased to $990, $940, $920, $850, $800 ...$1.The magnitude of the immediate rewards were presented in descending sequence. The immediate reward value on which the subjects revised their choice of reward from immediate to delayed is recorded and is referred to as the point of indifference. At the point of indifference, the subjective value of delayed and immediate rewards is equal. For each condition, the point of indifference was calculated at each of the six intervals of 6h, 1 day, 1 week, 2 months, 6 months, 1 year presented in the ascending order.

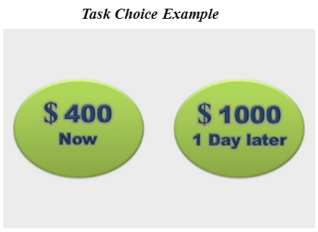
Results

We considered several models of discounting to index individual differences in temporal discounting behaviour. The goal of the present study was quantitative characterization of behaviour. In order to capture the result from the obtained data a few temporal discounting models were fitted to the discounting data. The present data was found to fit best for the hyperbolic model. This model has several advantages that make it popular across several human and animal studies (Green & Myerson, 2004). The hyperbolic model offers the simplest summary of discounting behaviour using a single individualized parameter (k). Individual subjects discounting factor (k) was estimated using the maximum likelihood principle. We assumed that subjects using a hyperbolic discounting function assigned value to the delayed option where the value of $A with delay of D days was given by

Value = A/ (1 + kD), (Eq. 1)

[D = measure of delay (in days), k = individual discounting parameter and Value = the discounted stimulus value] (Mazur, 1987)

A



B

Type of Stimulation	K	R^2
Active-Tdcs	0.023	0.97
Sham-Tdcs	0.073	0.89

C

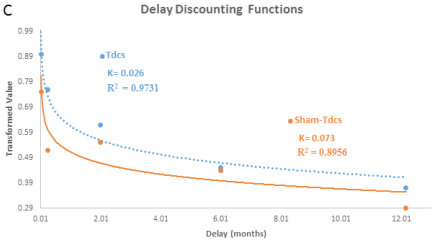


Fig.:1 | Task design and Behavioral Data. (A) Example display screens. (B) Showed Delay discounting parameters (*k*) for $1000 among the two subject groups presented with the R^2 values, (C) Choice curve displaying the subjective value expressed as a proportion of the $1,000 delayed amount shows the delay discounting functions (Eqs. 1) fit to the median indifference points.

While large K values indicated increase in impulsivity, smaller K values suggest patience. Fig.1 (B) contains individual k and R2-values for the delay discounting under both experimental conditions. Plotted in Fig. 1(C) are the median indifference values and best-fit hyperbolic discount functions for the delay discounting under both active and sham tDCS conditions. Fig.1 (B) also displays discounting parameter (k) for $1000 among subject groups. The values represent the median k values of the subjects within each group. Median values are presented with the R2 values, which represents the coefficients of determination for Eq. 1.

Temporal discounting and tDCS

Fig. 1(C) shows the median present values of $1000 delayed in time (six delay intervals) across groups. The median k values for each condition is presented in Fig.1 (B) for both conditions. Additionally, Fig.1 (B) shows correlation coefficients for the goodness of fit of Equation 1. It also describes accurately discounting of both monetary rewards and the coefficients of determination that was high (median r2 ≥ .097). Student t-test (pair-wise comparison) was used to evaluate the role of tDCS on intertemporal choice. The result of the test revealed a significant difference in the scores for tDCS (M= .026, SD= .01) and sham (M= .073, SD= .06) conditions; t (29) = 2.137, p > 0.05 which indicate that the anodal stimulation over left DLPFC decrease temporal delay discounting (Fig.2).

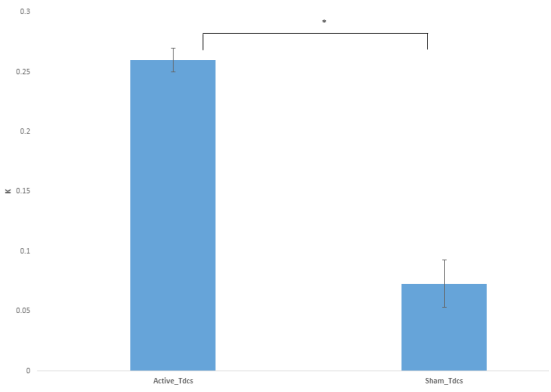


Figure-2 | Median *k* values of the subjects in Active-tDCS and Sham-tDCS group

Discussion

The present study investigated the effects of a single session of sham-controlled tDCS (anode over the left DLPFC, cathode over the right orbito-frontal cortex) on intertemporal choice behaviour as a measure of impulsivity in young adults. The main finding of the present study is that individuals who received direct current stimulation over the left dorso-lateral pre-frontal cortex preferred larger delayed rewards to smaller immediate rewards on the virtual task. In comparison, participants did not show this preference of rewards when they underwent sham stimulation or stimulation of alternate brain regions. These results suggest that the left dorso-lateral pre-frontal cortex has an important part in delay discounting choice behaviour. Thus, we can safely conclude that stimulating the left DLPFC alters individual decision making by increasing choice preference of larger delayed rewards to smaller immediate ones.

The above results suggest that stimulation of the left dlPFC modulates degree of impulsivity (as measured with the 'k' in the delay-discounting task) in younger adults. The result of our experiment is supported by previous research evidence that suggests anodal tDCS of the DLPFC upregulates the dlPFC activity that in turn increases the neural activity of the surrounding brain areas. The dlPFC is believed to exert top-down control over the "impulsive system" which leads to decreased likelihood for the existence of impulsive behaviour. These results support our hypothesis that this pattern of tDCS application would lead to increased neural activation of the dlPFC leading to reduced impulsiveness in terms of consistent choices for larger delayed rewards. The pattern of these findings suggests that the left dlPFC monitors self-control processes in intertemporal choice. Our results are consistent with the previous findings that outline how the left PFC exerts self-control in intertemporal choice (Hare, Hakimi, & Rangel. 2014). Additionally, our results are also in line with previous findings that reported the anodal stimulation of left DLPFC, which increases working memory (Zaehle, Sandmann, Thorne, Jäncke & Herrmann, 2011; Ohn et al. 2008; Andrews., Hoy, Enticott, Daskalakis, & Fitzgerald, 2011; Hoy, Arnold, Emonson, Daskalakis, & Fitzgerald, 2014),

executive function (Leite, Carvalho, Fregni, & Gonçalves, 2011) inhibition (Jeon, & Han, 2012) and control of negative emotion (Peña-Gómez, Vidal-Piñeiro, Clemente, Pascual-Leone, & Bartrés-Faz, 2011; Maeoka, Matsuo, Hiyamizu, Morioka, & Ando, 2012).

There is evidence of studies that are in direct opposition to the result of the present study. One such study done using transcranial magnetic stimulation (TMS) revealed that left dlPFC modulation does not lead to variation in choice behaviour on delay discounting tasks. We would like to state that TMS modulates the activity of a given cortical area by transiently disrupting brain activity which leads a temporary ‘‘virtual lesion’’ (Pascual-Leone, 1999). In direct opposition, tDCS activates the dlPFC that leads to hyperactivity in the region under investigation. Mull and Seyal (2001) and Mottaghy et al. (2000) using single pulse and 1 Hz repetitive TMS showed that stimulating left dlPFC increased task error when compared to controls (Mottaghy et al., 2000; Mull & Seyal, 2001). The reason behind this degradation in task performance is due to the transient disruption of the information processing capacity of the dlPFC that is bought on by TMS stimulation. Disruption of the function with low-frequency repetitive transcranial magnetic stimulation (rTMS) of left, but not right, lateral prefrontal cortex (LPFC) leads to increased choices of immediate rewards over larger delayed rewards (Figner et. al., 2010). One major point on which the present study differs from the TMS study is that the present study reported tDCS related improvement in task performance during anodal stimulation with a decrement in delay discounting while the TMS study reported increase in delay discounting behaviour after stimulating the left dlPFC. This observation is important as it shows that tDCS brain stimulation is different from that by TMS. This difference can be mainly attributed to the amount of electric current involved in these two techniques. TMS elicits neuronal depolarisations and induction of action potentials while tDCS causes a slight change in the resting potential of the stimulated cells (Creutzfeldt, Fromm, & Kapp 1962). This improves information processing by making neurons approach the depolarization thresholds. Nitsche and Paulus (2001) have shown that an 11 min of 1.0 mA current tDCS over the motor cortex can lead to shifts in excitability. Keeping this important observation in mind we provided a 24 hours delay between two successive testing sessions.

The present study also differs from the Hecht, Walsh, & Lavidor 2013 study. The present study only dealt with the left dlPFC which received anodal stimulation while the cathode was placed on the orbito-frontal region above the right eye. This way we only performed the unilateral stimulation of the left dlPFC while the Hecht, Walsh, & Lavidor 2013 performed a bilateral stimulation of both the right and left dlPFC. Thus, the present study differed from the Hecht, 2013 study on methodological grounds. Bilateral stimulation can affect a larger cortical network and may result in a different outcome than a unilateral and more circumscribed stimulation (Boggio et al., 2009; Penolazzi et al., 2010). Moreover, the magnetic stimulation used in both by Finger et al, 2010 and Cho at al., 2015 may lead to different physiological effects than our direct current stimulation in terms of differences in the size and depth of the brain regions affected (Boggio et al., 2009). Furthermore, two tDCS studies are not always comparable, since the extent of the physiological effects depends on both the current intensity and the electrode size. In the present study, we aimed to stimulate the dlPFC and accordingly used small sized electrodes. This might have led to increase in the current density but restricted the physiological effect to a more focused brain region (Nitsche et al., 2008). Future studies can be conducted to establish the exact stimulation techniques and protocols that can affect participants’ choices in delay discounting tasks.

The results of the present study are interesting, but they suffer from several limitations that follow the interpretation of results. First, the present study did not evaluate the likelihood of an interaction between discounting delay at a different level of probability. This can be evaluated in future studies under varying, uncertain levels (e.g. 0.40, 0.50, and 0.70) and delays. Second, the results of our study suggest that the effect of tDCS on brain activity depends on the polarity of the stimulation electrode (anodal stimulation hyperpolarizes

while cathodal stimulation depolarizes) (Nitsche et al., 2003). Future studies can be designed to test other combination (i.e. Cathodal dlPFC and bilateral PFC) of brain stimulation with tDCS using delay-discounting choice. Third, the tDCS has invariably low spatial resolution that hurts the process of targeting the appropriate area of activation using this method of brain stimulation. Stimulation of the DLPFC may co-activate other frontal regions such as the orbitofrontal/ ventromedial cortex because they are densely interconnected (Ghashghaei & Barbas, 2002) and spatially close. Large tDCS electrodes (35 cm2) suggest the possibility of co-activation of nearby areas to the dlPFC that could have confounded the present study result. This aspect could be a major focus of future studies.

In conclusion, the results of the present study suggest that anodal stimulation of the left dlPFC enhances delay discounting. The present study did not aim on evaluating therapeutic effect of tDCS, but we believe that our results should encourage further investigations for the use of tDCS in clinical applications. Our study results support for the investigation of modulation of dlPFC as a possible treatment for pathological high-risk takers (such as individuals with addiction).

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