Neuroscience Letters 674 (2018) 54–59

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Research article

Transcranial direct current stimulation of the medial prefrontal cortex modulates the propensity to help in costly helping behavior

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ARTICLE INFO

Keywords:
Transcranial direct current stimulation (tDCS)
Medial prefrontal cortex
Costly helping behavior
Decision-making

ABSTRACT

Social decision-making engages traditional decision-making processes (e.g. valuation), as well as social cognition processes (e.g. inferring the affective and mental states of another person). Neuroimaging and neuro-stimulation studies have suggested the involvement of the medial prefrontal cortex (mPFC) in a variety of social decision-making tasks. Yet no study has investigated the effect of the cortical excitability of mPFC in the decision-making of costly helping behavior. Here, we used tDCS to demonstrate the causal relationship between the cortical excitability of mPFC and costly helping decision-making. Subjects assigned to the anodal, cathodal and sham groups were required to decide whether they would like to cost their own money to relieve another subject (a confederate actually) from painful electrical shocks with a certain probability of success. Results showed that the subjects receiving anodal stimulation acted more prosaically than the subjects receiving cathodal stimulation. And this effect was only significant when the probability of success was high. We proposed that tDCS induced modulation of the cortical excitability, targeting the mPFC, can affect the prosocial propensity in costly helping behavior, and the possible underlying mechanisms were discussed.

1. Introduction

Helping behavior refers to voluntary actions intended to help or benefit other individuals or groups, which is a typical prosocial behavior [1]. Based on our daily experience, the offer of help is not always guaranteed, even when help is explicitly requested. People may decide to help or not to help in different circumstances, especially, when helping others is not in the interests of themselves and even be costly for them [2]. Helping behavior, especially costly helping behavior is actually, a social decision-making process [3–5]. Individuals would value the pros and cons to make a decision that affects both of the self and others.

Social decision-making is a complex process which must engage the process of social cognition (e.g. inferring the affective and mental states of another person), as well as the traditional decision-making process (e.g. valuation). In the case of costly helping decision-making, specifically, on the one hand, the decision depends on whether you would empathize or mentalize with the person in need. According to the "empathy-altruism hypothesis", helping behavior may be initiated when we feel empathy for the person, that is, feeling and understanding what that person is experiencing [6]. On the other hand, the decision also depends on the assessment of the situation, such as the cost and the probability of success of helping [7]. People are unlikely to decide to help if they believe their help is doomed to fail or the cost is beyond their range.

Therefore, decision-making of costly helping would involve both of the traditional decision-making brain network and the social cognition brain network [8,9]. It is noteworthy that one brain region plays a key role in both of the networks: the medial prefrontal cortex (mPFC). Previous studies systematically suggested that in the decision-making related process the activity of mPFC is responsible for the generating and computation of subjective values, regardless of reward types [10–13]. It was also consistently suggested that the mPFC plays a central role in understanding other's feelings, emotions and thoughts, especially during the affective theory of mind (ToM) [14]. Taken together, it was reasonable to assume that the cortical excitability of mPFC might be crucial in costly helping decision-making.

Transcranial direct current stimulation (tDCS) modulates the cortical excitability by passing a direct current between an anodal and a cathodal electrode. Anodal stimulation causes depolarization of the resting membrane potential, making the neurons under the electrode site more likely to fire, whereas cathodal stimulation leads to

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https://doi.org/10.1016/j.neulet.2018.03.027
Received 21 February 2018; Received in revised form 12 March 2018; Accepted 13 March 2018
Available online 14 March 2018
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hyperpolarization which results in the decrease of neuronal excitability [15,16]. This technique can provide insight into the role of cortical regions in cognitive functions by modulating neural excitability and observing the corresponding effects of the stimulation on the targeted [17]. Previous studies proved that using tDCS targeting in mPFC may modulate subjects' behavior in social decision-making tasks(for a review, see [16]).

However, how the excitability of mPFC may influence the costly helping behavior has not been investigated yet. The aim of the current study was to demonstrate the causal involvement of mPFC in the decision-making of costly helping behavior. The target electrode of tDCS was placed over the mPFC and the reference electrode was placed over visual cortex based on previous studies [18–20]. Two subjects with different roles would participant in the experiment each time. One was the "*decider*" while the other one was the "*pain-taker*". The *pain-taker* would receive a painful electrical shock in each given trial. Before the shock applied, the *decider* would have the chance to help the *pain-taker*. An offer with two aspects of information would be presented to the *decider*: 1) the money they need to spend if they choose to help; 2) the probability of successful helping. Based on the previous studies, the activations in the mPFC were suggested to provide the basis for one's "emotional bond" with other persons [21] and greater activity in mPFC was associated with higher levels of self-reported experienced empathy as well as with daily helping behavior [22]. And anodal tDCS stimulation applied on mPFC has also been suggested to increase the trustworthiness and altruism in social decision-making [23]. We, therefore, hypothesized that the anodal stimulation to mPFC would increase the propensity to help in this task and the cathodal stimulation to mPFC would show a reverse effect.

2. Method

2.1. Subjects

Sixty right-handed subjects (20.8 ± 0.33y (mean ± s.e)) with no history of neurological disorders, brain injuries or developmental disabilities participated in the experiment and got reimbursed for their participation. All subjects were screened for possible contraindications to tDCS and were gave written informed consent after they fully understood the task. All research procedures were approved by the Medical Ethical Committee of College of Psychology and Sociology at Shenzhen University according to the Declaration of Helsinki.

2.2. Design and procedure

This experiment was a single-blind, sham-controlled, mixed design with the cost and probability as the within-subject factors and the types of stimulation as a between-subject factor. Subjects were randomly assigned to one of the three stimulation conditions (10 male and 10 females per group): anodal, cathodal, or sham stimulation. There was no significant difference in three groups with respect to age and empathic level (Table 1). A week prior to the experiment, the subjects were asked to fulfill the Interpersonal Reactivity Index (IRI) [24] to measure their empathy trait. Prior to the stimulation, subjects were given nine practice trials to ensure full understanding of the task. After the practice, tDCS stimulation was initiated. The stimulation was started 180 s before the task and lasted for as long as the individual subject worked on the task but no longer than 20 min.

A confederate design was used in this study. After the subject's arrival, the experimenter introduced the subject to a confederate with the same gender (two confederates with different gender were used in the experiment), who was described as another subject. The subject and the confederate draw lots that were manipulated so that the subject was always assigned to receive the tDCS stimulation (the *decider*) and the confederate was always assigned to be the *pain-taker*.

The subjects were led to believe that in each trial, a strong, noxious electrical shock would be delivered to the *pain-taker* (confederate). Before the delivery of the shock the *decider* would be presented with a chance to help the *pain-taker*. An offer would be proposed with two aspects of information: how much it would cost to help the pain-taker in this trial (three levels: low (1RMB, ∼0.16 dollar), median (5RMB, ∼0.79 dollar) and high (9RMB, ∼1.42 dollar)); how much of the probability of successful helping if they choose to help (three levels: low (10%), median (50%) and high (90%)). There were 9 different offers in total (Cost (3) × Probability (3)) and each offers repeated 15 times. A total of 135 trials were presented.

During the experiment, the confederate and the real subject sat in two separate rooms and the subjects were led to believe that the confederate would receive a painful electrical shock in each trial unless they successfully helped him/her. In reality, the confederate was not receiving any shocks during the experiment. The decider would wear noise-reduction headphones during the whole experiment. And they were informed that after the experiment, 15 trials would be randomly selected from the 135 trials and their payment would be calculated based on the selected trials. Notice that the money that subtracted from the decider's payment would only depend on the choice of the decider but not the outcome of the decision. Even if the help failed, the money would not be returned.

At the beginning of each trial, a white rectangle would appear in the center of the screen. The proportion of green area on the rectangle indicated the probability of success and the black number in the center indicate the cost (Fig. 1A). The subjects were instructed to press the button labeled "Y" (Yes) or "N" (No) to indicate their choices. The buttons labeled were actually the "F" and "J" on a keyboard and counterbalanced among subjects. The offer would last for maximum 5000 ms and disappeared when one of the two buttons was pressed. The subjects were informed that if they gave no response during 5s, the default choice would be "N" and a shock would be delivered. After the decision was made, a blank interval would last for 500 ms. Then a photo showing a hand attached with two electrodes (token from the setting of the electrical shock) would appear for 1000 ms. The subjects were told that we do not reveal the outcome of their decisions during the task because we don't want the outcome of the previous trial to influence their later decisions. We would tell them how many shocks the *pain-taker* received during the task afterward. The photo was used to indicate the possible shock(if they choose "N" or if their help failed then there would be a shock, otherwise, if their help succeeds then there wouldn't be any shock). There was an ISI of 1500 ms to 3500 ms between trials

Table 1
Subjects demographics for the anodal, cathodal and sham groups. Descriptive data are presented as mean ± s.e.

Stimulation type	Anodal (n = 20)	Cathodal (n = 20)	Sham (n = 20)	Statistics
Age(y)	20.41 ± 0.68	21.32 ± 0.89	20.80 ± 1.07	$F(2,57) = 2.56$, $p = 0.087$
Gender (male/female)	10/10	10/10	10/10	
IRI (total score)	65.55 ± 1.62	69.66 ± 2.34	66.20 ± 1.85	$F(2,57) = 1.201$, $p = 0.308$
Perspective Taking	16.80 ± 0.54	18.75 ± 0.73	17.33 ± 0.38	$F(2,57) = 0.785$, $p = 0.487$
Empathic Concern	17.40 ± 0.79	18.35 ± 0.89	18.40 ± 0.79	$F(2,57) = 0.465$, $p = 0.630$
Personal Distress	15.75 ± 0.67	16.10 ± 0.91	14.85 ± 0.73	$F(2,57) = 0.685$, $p = 0.508$
Fantasy	15.60 ± 1.03	16.35 ± 1.05	16.50 ± 1.02	$F(2,57) = 0.217$, $p = 0.806$

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