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Brain Stimulation Over the Frontopolar Cortex Enhances Motivation to Exert Effort for Reward

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ABSTRACT

BACKGROUND: Loss of motivation is a characteristic feature of several psychiatric and neurological disorders. However, the neural mechanisms underlying human motivation are far from being understood. Here, we investigate the role that the frontopolar cortex (FPC) plays in motivating cognitive and physical effort exertion by computing subjective effort equivalents.

METHODS: We manipulated neural processing with transcranial direct current stimulation targeting the FPC while 141 healthy participants decided whether or not to engage in cognitive or physical effort to obtain rewards.

RESULTS: We found that brain stimulation targeting the FPC increased the amount of both types of effort participants were willing to exert for rewards.

CONCLUSIONS: Our findings provide important insights into the neural mechanisms involved in motivating effortful behavior. Moreover, they suggest that considering the motivation-related activity of the FPC could facilitate the development of treatments for the loss of motivation commonly seen in psychiatric and other neurological disorders.

Keywords: Cognitive effort, Decision making, Frontal pole, Physical effort, Reward, tDCS

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From sports to academic achievement, motivation determines the level of energy or other resources a person will invest toward achieving a valued outcome and is thus a core aspect of goal-directed behavior. Conversely, loss of motivation in goal-directed behavior is a defining (negative) symptom of several psychiatric and neurological disorders (1–3). Thus, a better understanding of the brain mechanisms involved in motivation and in driving some humans to work harder than others for the same rewards is important for both basic and clinical science.

One brain region that might play a key role in motivation is the frontopolar cortex (FPC). Thought to lie at the top of the hierarchy of a prefrontal control network (4,5), the FPC is well positioned to support a multipurpose construct such as motivation. Activation in the FPC, as well as in other hubs of the prefrontal control network, correlates with individual measures of motivation and with successful performance in incentivized tasks requiring high cognitive effort (6,7). However, since this research examined brain activation correlated with successful performance of cognitively demanding tasks, it is unclear whether the observed FPC activity supports cognitive processes required for task performance or whether it plays a more direct role in generating or evaluating motivation itself. If the FPC facilitates successful goal-directed behavior by representing higher-order goals that should be pursued during a given task (6,7), we expect FPC activity to increase the willingness to engage in effort to attain the current task goal. This expectation is also suggested by recent studies showing the FPC to be crucially involved in overcoming various types of costs to pursue more-valuable goals (8–13). By extension, the enhanced activation of the FPC during incentivized cognitive tasks (6,7) might thus be explained by its more general role in increasing the value of goals against the required costs. The first aim of this study was therefore to test the FPC's potential role in motivating effortful goal-directed behavior in the absence of requirements for high levels of cognitive control or concerns about accurate task performance.

Until now, the FPC has been associated primarily with effort related to cognitive control. A second question we addressed was therefore whether and how the FPC may also contribute to motivating physical effort. In other words, does the FPC have a general role in the domain of motivation? Current evidence on this question is mixed, as effort costs in cognitive versus physical tasks have been associated with either common or distinct neural activity in different reports (14–16). Thus, it remains unclear whether overlapping or dissociable neural mechanisms are responsible for motivating the exertion of cognitive and physical effort.

To test the role of the FPC in motivation to exert cognitive or physical effort, we applied transcranial direct current stimulation (tDCS) over the right FPC while participants decided whether or not to engage in cognitive or physical tasks that yielded varying levels of reward. tDCS is a noninvasive brain stimulation technique that can be used to either increase or decrease the neural excitability of a brain region (17). This approach allowed us to examine the impact of tDCS targeting the FPC on the willingness to engage in rewarded cognitive and physical effort.

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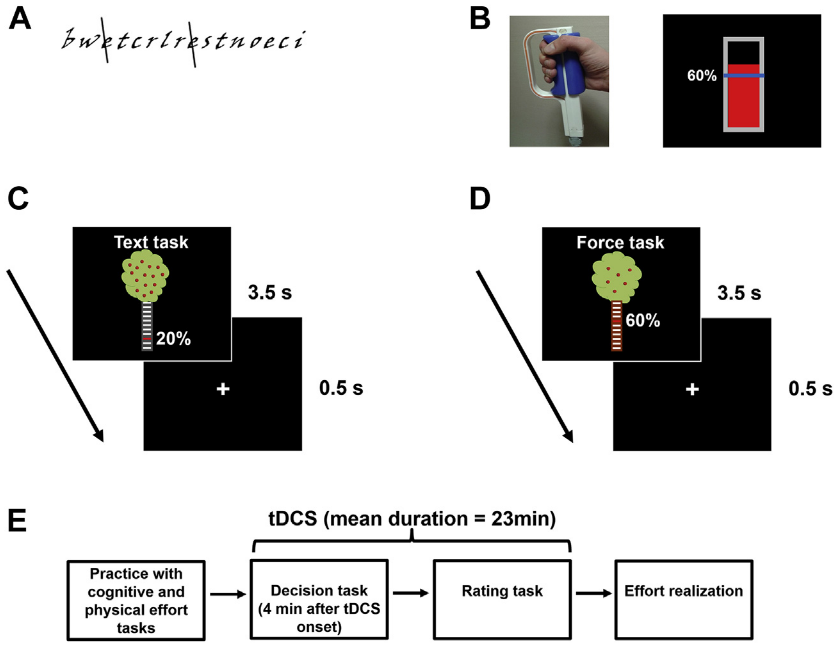

Figure 1. Effort types, task design, and task validation. **(A)** Cognitive effort consisted of letter identification in a demanding text task (crossing out letters *e* unless one of the two letters before or after was a vowel), and effort levels varied as a function of text length. **(B)** Physical effort consisted of squeezing an isometric handgrip dynamometer, and effort levels varied as a function of the force required (60% maximum strength in the displayed example). **(C, D)** Example decision trials of decision tasks. In each trial, participants decided whether to accept or reject offered combinations of **(C)** cognitive effort or **(D)** physical effort and monetary reward. The magnitude of the reward at stake was illustrated by the number of apples on the tree; the required effort was indicated by a height mark on the trunk. The effort type was indicated above the tree ("Text task" for cognitive effort, "Force task" for physical effort). The tree was presented for 3.5 seconds; during this period, the participant had to decide whether to accept the offer. **(E)** An overview of the experimental procedure. Participants first exerted cognitive and physical effort on sample tasks, which allowed them through experience to understand the meaning of different effort levels of both effort types that would be used in subsequent tasks. Next, participants performed the decision tasks and the rating tasks while receiving anodal, sham, or cathodal transcranial direct current stimulation (tDCS). At the end of the experiment, one choice of the decision task was randomly selected and participants had to exert the selected amount of cognitive or physical effort.

METHODS AND MATERIALS

Participants

A total of 141 healthy humans (mean age 22.78 years, range 18–34 years; 71 female participants) participated in the study after they gave voluntary informed consent. Power calculations based on two previous studies administering FPC tDCS in human decision-making tasks (10,11) suggested a minimum sample size of 42 participants per tDCS group to be required for an 80% probability of finding a significant effect ($\alpha = .05$). One participant was excluded because his German-language skills were insufficient for understanding the instructions for the cognitive-effort task, another participant because the tDCS electrodes slipped during the experiment, and a third because of an unusually high number of response omissions (31% of all trials; all other participants' mean omission rate = 0.7%, standard error of mean = 0.1%). Thus, the data of 138 participants were entered into the statistical analyses (anodal tDCS, $n = 43$; cathodal tDCS, $n = 47$; sham tDCS, $n = 48$). The rating task data of one participant were lost as a result of technical problems, but his choice data from the decision tasks were included in the analyses. Participants received 60 Swiss francs for their participation plus a monetary bonus depending on their choices (see below). The study was approved by the local ethics committee (Cantonal ethics committee Zurich).

Stimuli and Task Design

In each trial, participants decided whether or not they were willing to exert a level of cognitive or physical effort to obtain a monetary reward (Figure 1A, B). For physical effort exertion, they had to squeeze a dynamometer for 20 seconds with 20% to 100% of their maximum grip force, whereas for cognitive-effort exertion, they had to cross out all letters *e* in a text composed of random letter sequence groupings (i.e., pseudowords) according to a demanding rule (the two letters before and the two letters after an *e* must not be vowels). Here, 100% cognitive effort meant that participants had to work on 40 lines of text, a value that had been determined in pilot experiments.

The magnitude of the monetary reward was symbolized by a number of red apples (0, 1, 3, 6, 9, or 12 apples) on a tree; one apple was exchanged for 0.1 Swiss francs after the experiment. The required effort was indicated at the tree trunk (0%, 20%, 40%, 60%, 80%, or 100% effort). Participants indicated their choices to accept or reject the presented offer via key press during the 3.5-second presentation of an offer. The next offer was presented after an intertrial interval of 0.5 second (Figure 1C, D).

Note that the goal of the study was to test the FPC's role in deciding whether a reward is worth the effort required to obtain it, not in the actual production of effort after the decision to engage in it. To avoid exhaustion, which might affect cost-benefit computations during decision making, participants did not have to exert the effort immediately after having accepted an offer. Instead, at the end of the experiment, we randomly selected one trial from both effort decision tasks and implemented the chosen decision (Figure 1E). If participants had accepted the chosen offer, they had to exert the corresponding amount of cognitive or physical effort to obtain the additional monetary reward. If they had rejected the offer, they received no additional reward after the experiment. Accordingly, we instructed participants to make each decision during the tasks as if it would be the one randomly selected at the end, because each decision had an equal chance of being