Behavioural Brain Research 257 (2013) 208–214

Contents lists available at ScienceDirect

Behavioural Brain Research

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

Research report

Anodal tDCS over SMA decreases the probability of withholding an anticipated action

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HIGHLIGHTS

- Stop-signal anticipation-timing performance was examined following tDCS over SMA.
- Anodal tDCS led to a decreased probability of inhibition on stop trials.
- Anodal tDCS resulted in early response initiation compared to pre-tDCS.
- No change in the probability of inhibition was found following cathodal tDCS.

ARTICLE INFO

Article history:
Received 30 July 2013
Received in revised form 9 September 2013
Accepted 14 September 2013
Available online 21 September 2013

Keywords:
tDCS
Supplementary motor area
Anticipation-timing
Inhibition

ABSTRACT

Previous research has shown that the supplementary motor area (SMA) is critical in movement inhibition. Recently it was shown that applying transcranial direct current stimulation (tDCS) over SMA affected participants' ability to inhibit their movement in a stop-signal reaction time task (Hsu et al. [11]). Of interest in the current study was whether modulating SMA excitability using tDCS would have similar effects in an anticipation-timing stop-signal task. Participants performed 2 sessions each consisting of a pre- and post-tDCS block of 160 trials in which they were instructed to extend their wrist concurrently with the arrival of a pointer to a target (i.e., a clock hand reaching a set position). In 20% of trials (stop trials) the pointer stopped 80, 110, 140, 170, or 200 ms prior to the target, and on these trials participants were instructed to inhibit their movement if possible. Anodal and cathodal tDCS (separated by at least 48 h) was applied for each participant between the pre- and post-tDCS blocks. No change in the proportion of successfully inhibited movements on stop trials was found following cathodal tDCS ($p > .05$). However, anodal tDCS resulted in a decreased proportion of successfully inhibited movements on stop trials ($p = 002$), and an earlier movement onset on control trials ($p < .01$). This suggests that the SMA may be more involved in initiation than in inhibition of anticipatory movements. Furthermore these data suggest that differences in initiation and inhibitory processes exist between stop-signal reaction time and anticipation-timing stop-signal tasks.

1. Introduction

Anticipation of external events allows people to act concurrently with, instead of in reaction to, environmental stimuli. However, such actions must sometimes be inhibited. For example, a "checked swing" in baseball involves both anticipating the arrival of the ball and later inhibiting the swing. One method that has been used to investigate these types of actions in the laboratory is an anticipation-timing task where a stop-signal is occasionally presented. Slater-Hammel [1] had participants perform a task in which they were instructed to lift their finger from a signal key concurrently with the arrival of a revolving pointer to an indicated position. If the pointer stopped prior to the target position, then participants were told to try to inhibit the finger lift. The probability of successfully inhibiting the movement at various latencies was determined by manipulating the times at which the pointer stopped with respect to the anticipated "go." Participants were able to successfully withhold the action in 50% of trials if the pointer stopped 166 ms prior to the target; after this time the movement was committed to action in a majority of trials–which Slater-Hammel termed the "point of no return" [see also 2]. The processes underlying stop-signal tasks have been represented as a horse race between the processes responsible for initiating the

Abbreviations: ECR, extensor carpi radialis longus; FCR, flexor carpi radialis; RT, reaction time; SSRT, stop-signal reaction time.

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http://dx.doi.org/10.1016/j.bbr.2013.09.030

action and processes responsible for inhibiting the action, such that the movement is or is not carried out depending on which of the two processes reaches the response decision threshold first [3].

In anticipation-timing tasks, activation related to motor preparatory processes appears to be delayed until shortly (150–300 ms) prior to the anticipated time of response [4,5]. Motor inhibitory activation appears to involve a similarly short time-course when presented in an anticipation-timing paradigm that includes a stop-signal [6]. In these types of tasks, motor inhibition is suggested to occur via a reduction in excitability of the active motor areas specific to the action coupled with increased activity in inhibitory brain areas [6]. One cortical area suggested to mediate the inhibitory processes is the supplementary motor area (SMA) [7,8]. The SMA can be divided into two motor subsections: the posterior portion (SMA-proper) and the anterior portion (pre-SMA) [9], both of which have been shown to be involved in movement inhibition. For example, functional magnetic resonance imaging (fMRI) was used to show that the SMA was active in inhibiting the execution of movements that were primed in advance using motor imagery [10] or passive movement [8]. In addition, fMRI data showed that both the pre-SMA and the SMA-proper showed increased activation during a muscle relaxation task compared to an active contraction task [11]. Notably, other imaging studies found that the pre-SMA was involved in inhibiting movement during a stop-signal reaction time (SSRT) task – where an imperative "go" signal is presented and sometimes followed at short latency by a stop-signal [12,13]. Specifically, increased activation in pre-SMA correlated positively with successful inhibitory control during the stop-signal task [14]. Together, these data suggest that although the two areas are distinct, they may cooperatively play a role in motor inhibition [11].

Given the evidence for strong involvement of the SMA in motor inhibition, it was of interest whether modulating SMA excitability would affect stopping performance in an anticipation-timing task involving a stop signal [e.g., 1]. Transcranial direct current stimulation (tDCS) is a non-invasive technique used to modulate neural activity in which a weak electrical current is applied over the scalp for short periods of time. Several recent neurophysiological studies have shown that stimulation results in polarity-dependent modulation of the underlying brain tissue. Using TMS to index changes to corticospinal excitability following tDCS over primary motor cortex, it has been shown that cathodal tDCS hyperpolarizes the neurons underlying the site of stimulation, leading to decreased excitability, while anodal stimulation depolarizes and increases the excitability of the tissue [see 15 for a review]. Moreover, recent findings have also shown that changes in excitability can in turn influence functions associated with the modulated cortical areas. As such, tDCS can be used to elucidate the function of specific brain areas in the production of actions. For example, when tDCS was applied over pre-SMA during a SSRT task the probability of a successfully inhibiting action after the presentation of a stop-signal was increased following anodal tDCS and decreased following cathodal stimulation [16].

It has been suggested that the involvement of inhibitory neural circuits may vary depending on task requirements. For example, inhibitory circuits involved in go/no-go tasks overlap with but are distinct from those involved in stop-signal tasks [17]. More relevant to the current experiment, because the involvement of inhibitory neural circuits may differ between stop-signal tasks with different timing parameters (i.e., anticipation-timing with stop-signal vs. SSRT) it was thought that modulating SMA during an anticipation-timing task would elucidate differences between them. Therefore, the current study investigated how applying tDCS over SMA affected performance in an anticipation-timing task involving a stop-signal. Seing as SMA is thought to contribute to action inhibition it was hypothesized that anodal tDCS applied over the SMA would result in a higher proportion of stopped responses at the various tested times; that is, an increase in the ability to inhibit an anticipated action. Conversely, it was thought that cathodal tDCS would result in a decrease in successful inhibitions.

2. Materials and methods

2.1. Participants

Twelve neurologically healthy volunteers (6 M, 6 F; 26.9 ± 11.4 years) participated in the study. Testing was performed in two sessions, separated by a minimum of 48 h, for all participants. Written informed consent was obtained before beginning testing; the study was conducted in accordance with University of Ottawa Research Ethics Board, and conformed to the most recent version of the Declaration of Helsinki.

2.2. Apparatus

Participants were seated facing a computer monitor at eye level, approximately 50 cm away. The right forearm was placed in a custom-made manipulandum with a padded concave armrest with the right shoulder flexed and abducted approximately 15°. Two Velcro straps were used between the wrist and elbow to secure the arm in place. The wrist was semi-pronated with the palm facing inward in a neutral position (neither flexed nor extended), and the hand was secured to a separate swivelling rest, with the axis of rotation at their wrist. As such, participants' wrist movements were restricted to flexion and extension.

2.3. Task

Participants performed an anticipation-timing task involving a targeted wrist extension coincident with a clock hand arriving at a predefined location. A circle similar to a clock face (10 cm in diameter) was displayed with the numbers 1 through 10 evenly spaced around its perimeter starting at the 12 o' clock position (see Coxon et al. [6] for a figure showing a similar display). At the beginning of each trial, a tone sounded and the words "Get Ready" appeared at the centre of the screen below the circle, indicating to the participant that their wrist should be at the neutral home position (neither flexed nor extended). The "Get Ready" disappeared after 1000 ms and a clock hand began rotating clockwise around the circle, starting at the number 1 and completing the rotation in 1000 ms. Participants were to perform a 20° wrist extension movement as quickly and accurately as possible coincidently with the arrival of the clock hand at the number 8 (which was indicated by a red arrow). Participants were instructed that occasionally the clock hand would stop before reaching the target location and that on these trials they should try to inhibit their movement if possible. After each trial, participants were given feedback regarding their timing accuracy and awarded points based on timing performance to encourage accuracy. Points were given when displacement onset occurred within ±15 ms of the clock hand arriving at the target (1 point per ms below 15), and were subtracted when displacement onset occurred more than 50 ms early or late. Accuracy feedback and a running total of points awarded were displayed for 3 s, followed by the beginning of the next trial. Throughout all trials, participants were notified if their movement amplitude error was greater than 10° and were also verbally encouraged to time their movements as accurately as possible with the goal.

In each session participants performed 20 practice trials which were followed by a pre-tDCS testing block. The pre-tDCS block consisted of 160 anticipation-timing trials, in which on 25% of trials, the clock hand stopped 80, 110, 140, 170 or 200 ms prior to arriving to the target position. These "stop trials" occurred randomly