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Cathodal transcranial direct current stimulation over right dorsolateral prefrontal cortex improves language control during language switching

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ABSTRACT

Currently, there is increasing attention on how to best improve language control efficiency and minimize cross-language interference in bilinguals. Previous studies have demonstrated that right dorsolateral prefrontal cortex (rDLPFC) plays an important role in inhibiting unrelated stimuli. The current study applied transcranial direct current stimulation (tDCS) during language switching to determine whether modulation of rDLPFC would affect language control mechanisms. All the participants have undergone three types of stimulations: cathodal stimulation, anodal stimulation and sham stimulation. The sequence of three stimulations was counterbalanced across participants. After each stimulation, participants performed picture naming task for language switching. Unbalanced bilinguals exhibited a larger late positive component (LPC) in switching to the weaker language than to the dominant one and similar L1 and L2 switch costs only in the cathodal tDCS (C-tDCS) session. Further analyses showed that the differences of switch costs (L1 switch costs – L2 switch costs) in the C-tDCS session were smaller than in the sham-tDCS (S-tDCS) session. Results were largely consistent with the assumption that cathodal stimulation improving inhibitory control abilities of unbalanced bilinguals to help them better inhibit interference. Another possibility is that cathodal stimulation also worked in other brain areas (e.g., supplementary motor area), which potentially altered unbalanced bilinguals' speech planning or abilities to encode task sets.

1. Introduction

Bilinguals often experience interference from the unintended language during daily communication. The process of effectively learning and using the target language via suppression of the non-target language is referred to as language control [1–4]. Previous studies have indicated that the right dorsolateral prefrontal cortex (rDLPFC) plays an important role in inhibiting unrelated stimuli [2,5–7]. Language switching paradigms are typically utilized to investigate bilinguals' language control mechanism [3,6,8–10]. Here, we aimed to apply transcranial direct current stimulation (tDCS) over the rDLPFC during language switching to determine whether the modulation of the area improves language control efficiency.

The Inhibitory Control (IC) model postulates that inhibition functions crucially during selecting the intended language task schema (i.e., selecting an appropriate language according to the language context, inhibiting the non-target language, e.g., L1, L2) or target lemma (i.e., retrieving a target lemma while suppressing the non-target one, e.g., 苹果, apple) [11]. The model assumes that the amount of inhibition associates with language activation. The more active the language is, the more inhibition will be used. Specifically, for unbalanced bilinguals, because of greater activation of the L1 compared to the L2, more inhibition will be required during L2 production to reduce L1 interference than vice versa. In turn, more inhibition will persist into the next trial, and thus it should be more difficult to overcome inhibition in an L1 switch trial than in an L2 switch trial. That is, switching to the L1 will require more time than switching to the L2. Therefore, for unbalanced bilinguals, L1 switch costs are larger than L2 switch costs, exhibiting asymmetrical language switch costs. In contrast, balanced bilinguals with similar two or more language proficiency apply similar amount of inhibition when switching to any one of the language. Hence, similar switch costs between L1 and L2 are observed, which is termed symmetrical language switch costs [6,8,9].

Event-related potentials (ERP) studies often report the N2 or the late positive component (LPC) as the function of inhibitory control. Some studies presented the cue (e.g., different colors indicate different languages to name pictures) and stimulus pictures simultaneously and found that switching to L2 rather than to L1 elicited a more negative-

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going N2. They interpreted this as more inhibition was used to suppress interference from L1 [12]. To obtain the precise time course of language control, some studies presented the cue and stimulus pictures separately. They observed that L2 switch trials induced a more negative-going N2 than L2 repeat trials, or L2 trials elicited a more negative-going N2 than L1 trials in the cue-locked process, indicating that the N2 component reflects attentional control of the language task schema rather than inhibition of the non-target language [13–16]. Furthermore, switch trials induced a more negative-going N2 than repeat trials, or L2 switch trials elicited a larger LPC than L1 switch trials in the stimulus-locked process, indicating inhibition may play a role of suppressing non-target lemma [10,13,14,17,18].

Altogether, language control likely works through the inhibition of the non-target language task schema and/or non-target lemma to some extent, and this inhibition is indexed by the N2 or LPC. We wanted to explore whether the time course of language control would be affected when stimulated by tDCS. Previous studies have demonstrated that cathodal stimulation did not always degrade cognitive performance [19–21]. Consequently, existing researches focused mainly on whether tDCS was an effective method without dissociating the impact of different types of stimulation. Because one cannot be certain at this point which stimulation type improves language control, anodal, cathodal and sham stimulation were all used during a language switching task.

The current study attempted to use tDCS, a noninvasive and safe cortical stimulation technique, to modulate the excitability of rDLPFC by adjusting the polarity of a weak current flow, and thereby improving language control efficiency during language switching. The present study's procedure is presented in Fig. 1. We asked unbalanced bilinguals to receive interval sessions of anodal tDCS (A-tDCS), cathodal tDCS (C-tDCS) and sham tDCS (S-tDCS) once a week, totaling in three weeks for each participant. After each tDCS session, all participants performed a picture naming task in the L1 or L2 according to cues. According to IC model [11], unbalanced bilinguals should be subject to interference with L1 task schema and/or lemma when switching to the L2. Anodal stimulation to the rDLPFC is postulated to enhance bilinguals' inhibitory control abilities and to further suppress the interference. In particular, switching to L2 should show a more obvious N2 and/or LPC with symmetrical switch costs. Conversely, the C-tDCS should weaken inhibitory control abilities and degrade performance on suppressing interference. This should result in asymmetrical switch costs. The sham stimulation to the rDLPFC should result in little change. We hypothesized that the results would be intermediate between anodal and cathodal stimulation. According to our knowledge, this is the first study to attempt to improve language control efficiency by means of tDCS.

Table 1
Participants' characteristics.

Selfrating	L1 (Chinese)	L2 (English)
AOA		8.82(2.22)
Listening	5.41 (0.66)	3.54 (0.84)
Speaking	4.92 (0.78)	3.25 (0.85)
Reading	4.59 (1.34)	2.79 (0.88)
Writing	4.50 (1.14)	3.08 (1.38)
OPT		36.5 (3.85)
LexTALE		31.62 (3.68)

2. Method

2.1. Participants

Thirty undergraduate students recruited from Liaoning Normal University participated in the study. They were all right handed, native Chinese speakers with normal or corrected-to-normal vision and used English as a second language. None of the participants had neurological or psychological impairments or had used psychoactive medication. All participants signed an informed consent prior to participating in the study. This protocol was approved by the Institutional Review Board at School of Psychology, Liaoning Normal University. Data from six participants were eliminated: six due to excessive EEG artifacts. The final sample consisted of 24 participants (9 male), age from 18 to 26 years old ($M = 22.04 \pm 2.3$ years).

Table 1 provides the age of L2 acquisition (AOA) and the self-rated language skills (6-point scale: 1 = "quite poor", 6 = "highly proficient") of the participants. Paired-samples *T*-test revealed a significant difference between the proficiency rating of L1 and L2 for all four skills: listening, $t(23) = 11.75$, $p < 0.001$; speaking, $t(23) = 9.41$, $p < 0.001$; reading, $t(23) = 6.79$, $p < 0.001$; writing, $t(2) = 5.72$, $p < 0.001$. These results showed that participants were unbalanced bilinguals with intermediate L2 proficiency. Furthermore, Table 1 shows the average scales of L2 proficiency in LexTALE [22] (maximum score 100 points) and the Oxford Placement Test [23] (OPT, maximum score 50 points). Self-rated language skills reports and average OPT scores were analogous to previous studies of intermediate proficient Chinese-English bilinguals [13,14,24].

2.2. Language switching materials

We used a picture-naming task during language switching. Stimuli consisted of 72 black-and-white line drawings with a size of 15 cm × 15 cm. These images were selected from the Snodgrass and Vanderwart's photo gallery, which was standardized by Zhang and Yang [25]. The Chinese names of all pictures were two-character words, and their English equivalents were either one- or two-syllable words with 3–6 letters. A separate group of 35 intermediate proficient Chinese

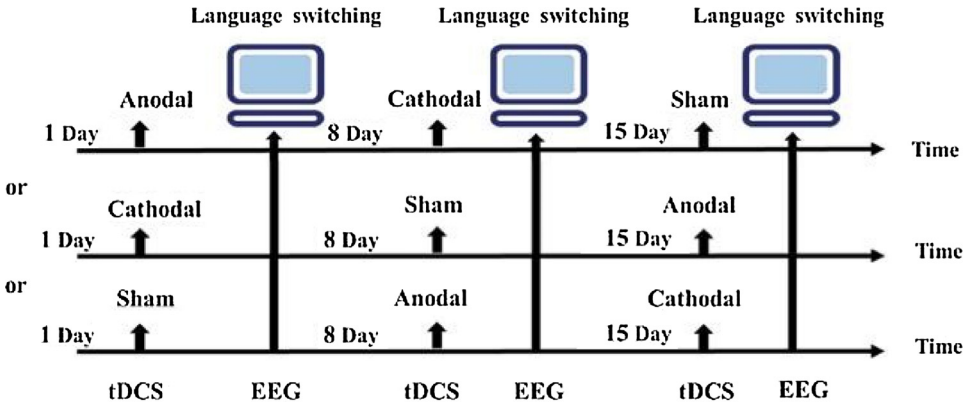

Fig. 1. Experiment procedure. The three sessions of anodal, cathodal and sham stimulation and language switching task were counterbalanced across participants. For example, participant A received the anodal stimulation in day 1 and completed language switching task. One week later (day 8), the same participant received the cathodal stimulation and completed the second language switching task. One week later (day 15), this participant received the sham stimulation and completed the last language switching task. Other participants received stimulations and finished tasks in a different sequence.