Is inhibition involved in voluntary language switching? Evidence from transcranial direct current stimulation over the right dorsolateral prefrontal cortex

Huanhuan Liu [a], Jing Tong [a], Angela de Bruin [b], Wanqing Li [a], Yuying He[a], Baike Li[a]

[a] Research Center of Brain and Cognitive neuroscience, Liaoning Normal University, Dalian, 116029, China.

[b] Department of Psychology, University of York, York, United Kingdom

Abstract: How do bilinguals freely switch languages in daily life (i.e., voluntary language switching)? Does this involve inhibition of cross-language interference, or does easier lexical access to specific words directly trigger switches to another language? To reveal the underlying mechanism of voluntary language switching, the current study applied transcranial direct current stimulation (tDCS) over the right dorsolateral prefrontal cortex (rDLPFC), an area associated with inhibitory control, to investigate whether and how inhibitory control is involved in voluntary language switching. Interestingly, during the A-tDCS and C-tDCS sessions, bilinguals showed faster naming latencies in repeat trials compared to switch trials, indicating a switch cost. Moreover, the cathodal stimulation exhibited a larger LPC in switching to L2 compared to switching to L1. In contrast, the S-tDCS (sham) session showed no switch cost, faster switch naming latencies compared to the A-tDCS and C-tDCS sessions, and little differences in LPC between switch and repeat trials. Together, these findings suggest that modulating inhibition-related brain regions interferes with voluntary language switching.

Key words: Voluntary language switching, Transcranial direct current stimulation, Inhibitory control, EEG, Late positive component

1. Introduction

In daily life, bilinguals often mix words from another language freely into their mother tongue (e.g., Chinese: 今天特别 happy — English: I am very happy today). This phenomenon of voluntarily mixing two languages is a natural example of language switching, which is also referred to as voluntary language switching (Blanco-Elorrieta & Pylkkänen, 2018; Gollan & Ferreira, 2009;

Gollan, Kleinman, & Wierenga, 2014; Kleinman & Gollan, 2016; Seo, Stocco, & Prat, 2018). Why do bilinguals, often seemingly freely, switch between languages?

Most studies on voluntary language switching are behavioral experiments. They instruct bilinguals to freely use a language to name pictures (de Bruin et al., 2018; Gollan, Kleinman, & Wierenga, 2014; Gollan & Ferreira, 2009, experiment 1) or while using each language approximately half of the time (Gollan & Ferreira, 2009, experiment 2). If bilinguals name pictures in the same language in two consecutive trials, the second trial is called a repeat trial. In contrast, if different languages were used in two consecutive trials, the second trial is termed switch trial. Some voluntary language switching studies have found switch costs (i.e., slower responses on switch trials) (e.g., de Bruin et al., 2018; Gollan & Ferreira, 2009). In cued switching tasks, instructing bilinguals when to switch languages, switch costs have been linked to inhibitory control. According to the Inhibitory Control mechanism, the dominant language will interfere during switches to the weaker language, requiring more inhibition of the dominant language (Green, 1998). It remains an open question whether inhibitory control is also involved in voluntary language switching.

To reveal the underlying mechanisms of voluntary language switching, Gollan and Ferreira (2009) looked at the characteristics of pictures that were never, sometimes, or often named in Spanish by English-dominant bilinguals. Easier pictures (e.g., those with a higher frequency) were named relatively more often in the non-dominant language, indicating that bilinguals chose the first language (L1) for words with low accessibility and the second language (L2) for words with high lexical accessibility. This suggests that the ease of lexical access affects language choice in voluntary switching paradigms. Unbalanced bilinguals furthermore showed switch costs in both languages and a reversed dominance effect with faster responses in L2 than L1. This reversed dominance effect may be due to unbalanced bilinguals proactively inhibiting interference from the L1, leading to overall slower responses in the L1 (cf. Kleinman & Gollan, 2018). This suggests that inhibitory control may play a role during voluntary language switching in unbalanced bilinguals.

Furthermore, Gollan, Kleinman, and Wierenga (2014) found that switch costs do not disappear when lexical repetition can facilitate lexical access. They used 8 pictures as stimuli whose names were high-frequency words and the same pictures were named several times in both a voluntary and a cued language switching task. Overall naming latencies during voluntary language switching were faster than during cued switching, but the voluntary task showed a reversed dominance effect and similar switch costs as in the cued switching task. This indicates that inhibitory control mechanisms may be involved in the two types of language switching. De Bruin et al. (2018) also confirmed the finding that both inhibitory control and lexical access may play a role in voluntary language

switching. They asked early high-proficient bilinguals to name pictures voluntarily or according to the cue. Language choice in the voluntary task was related to lexical access such that a bilingual was more likely to name a picture in one language if they were slow to name it in the other language. At the same time, switch costs were observed in both the voluntary and cued task, suggesting that although lexical access participates in voluntary language switching, the role of inhibitory control should not be ignored.

However, others have not observed differences between switch trials and repeat trials, i.e., no switch costs (Blanco-Elorrieta & Pylkkänen, 2017; Kleinman & Gollan, 2016). Kleinman and Gollan (2016) instructed their bilingual participants to choose one language for each picture and to then use that language to name the particular picture in the rest of the task. Following these instructions, bilinguals did not show a switch cost. These findings suggest that lexical access affects language switch costs, while top-down inhibitory control processes may play less of a role. Furthermore, Blanco-Elorrieta and Pylkkänen (2017) also found that inhibitory control is not necessary by comparing artificial cued and natural voluntary language switching. Colors were used as artificial cues to indicate the naming language. In the more natural conditions, faces of monolinguals required bilinguals to use a specific language while faces of bilinguals meant that the bilingual could voluntarily use one of the two languages. As expected, the natural cues (monolingual and bilingual faces) did not elicit a switch cost while the artificial cues did. Therefore, bilinguals appeared to be able to switch languages without inhibition.

Taken together, some studies found that even voluntary language switching produces switch costs, which could indicate that bilinguals apply both inhibitory control and lexical access to achieve language switching (de Bruin et al., 2018; Gollan & Ferreira, 2009; Gollan, Kleinman, & Wierenga, 2014). Others did not obtain switch costs at all, and argue that switch costs were elicited by artificial cues (Blanco-Elorrieta & Pylkkänen, 2017), suggesting that inhibitory control can be suspended and that lexical access may govern voluntary language switching (Kleinman & Gollan, 2016). The question whether inhibitory control is involved in voluntary language switching thus remains open.

Next, in addition to differences in experimental design (e.g., controlling lexical accessibility, using special cues), most studies only used behavioural measurements. To our best knowledge, no studies have employed electroencephalogram (EEG) to capture the temporal fine-grained details of voluntary language switching. Using EEG helps to better observe the time course of how a lexical item comes to mind in one language but not the other. Besides, our recent work (Li, Liu, Pérez, & Xie, 2018) found that, in a cued switching task, switch costs decreased by applying transcranial direct current stimulation (tDCS) over the right dorsolateral prefrontal

cortex (rDLPFC), an area associated with inhibitory control. In a similar vein, we used EEG and tDCS to record stimulation of an inhibitory control area, and to assess how voluntary language switching is affected.

The current study

The current study asked unbalanced bilinguals to name pictures whose corresponding words were matched on familiarity between the dominant language (L1) and weaker language (L2). We applied tDCS on the rDLPFC, as was done previously in cued-language switching (Li et al., 2018), to investigate whether and how inhibitory control mechanisms are involved in voluntary language switching. All participants took part in three types of stimulations: anodal A-tDCS, cathodal C-tDCS and sham S-tDCS sessions. The sequence of the three stimulations was counterbalanced across participants. After each stimulation, the participant performed a picture naming task in which they could freely choose a naming language.

Based on previous studies (Gajewski, Stoerig, & Falkenstein, 2008; Verhoef, Roelofs, & Chwilla, 2010), we first focused on N2 and the late positive component (LPC) The N2 component has been associated with conflict detection and monitoring, which increases with higher cognitive control demands (Verhoef, Roelofs, & Chwilla, 2009, 2010), and response selection (Gajewski, Stoerig, & Falkenstein, 2008). The LPC belongs to a bigger family of positive components, such as the P300, which are more generally associated with episodic memory retrieval (Bakker, Takashima, van Hell, Janzen, & McQueen, 2015; Matsumoto, Iidaka, Haneda, Okada, & Sadato, 2005) or the integration of lexical information with semantic representations to form an updated concept (Berkes, Friesen, & Bialystok, 2018).

We hypothesized that i) if voluntary language switching recruits inhibitory control mechanisms, reversed dominance effects and switch costs should disappear after receiving tDCS. Meanwhile, stronger N2 effects that mirror cognitive control would reflect more efficient inhibition of the L1; ii) if voluntary language switching is not governed by top-down control processes, switch and repeat trials in both languages should show similar ERP results in the sham session.

To the best of our knowledge, the current study is the first to use electrophysiological evidence to study the mechanisms underlying voluntary language switching. This will reveal whether and how voluntary language switching is driven by top-down inhibitory control, providing a better understanding of language switching in more natural settings.

2. Method

2.1 Participants

Twenty-four participants from Liaoning Normal University took part in the current study. All were right handed with normal or corrected-to-normal vision and no history of neurological or psychological impairments or receiving treatment with any psychoactive medication. Chinese is their native language (L1) and English is used as the second language (L2). All participants signed written informed consent. The research protocol was approved by the Institutional Review Board at the School of Psychology, Liaoning Normal University. Data from four participants were eliminated due to excessive EEG artifacts. 20 participants were included for further analysis (12 females, $M = 24.2 \pm 1.1$ years).

To assess the participants' language proficiency, we used questionnaires enquiring about the age of L2 acquisition (AOA), and self-rated language skills. The ratings were provided using a six-point scale in which 6 indicated that L1/L2 knowledge were perfect, and 1 indicated no knowledge of L1/L2. In addition to self-rated measurements, language proficiency was measured through two objective measurements: LexTALE (maximum score 60 points; Lemhöfer & Broersma, 2012) and the Oxford Placement Test (OPT, maximum score 50 points; Allan, 1995). Table 1 shows the details of the above measurements. Paired sample T-tests revealed that the proficiency ratings were significantly higher for L1 than L2: listening, $t(19) = 6.31$, $p < .001$; speaking, $t(19) = 7.67$, $p < .001$; reading, $t(19) = -5.64$, $p < .001$; writing, $t(19) = 3.16$,$p = .005$. Thus, the participants were unbalanced bilinguals with weaker proficiency in L2 than in L1. Of interest was that the scores of self-rated language skills and the average scores on the OPT resemble previous research testing unbalanced Chinese-English bilinguals (Liu, Liang, Dunlap, Fan, & Chen, 2016; Liu, Xie, Zhang, Gao, Dunlap, & Chen, 2018).

Table 1. Participants' characteristics

Self-rating	L1(Chinese)	L2(English)
AOA		9.35 (2.39)
Listening	5.30 (.98)	3.75 (1.12)
Speaking	4.95 (.83)	3.80 (.62)
Reading	4.50 (1.28)	2.85 (.81)
Writing	4.60 (1.05)	3.60 (1.39)
Proficiency tests		
LexTALE		35.07 (4.91)
OPT		35.00 (6.54)

Further, we used the bilingual switching questionnaire (BSWQ) (Rodriguez-Fornells, Kramer, Lorenzo-Seva, Festman, & Münte, 2011) to quantify bilinguals' language switching rate in daily life. This questionnaire used a six-point scale with 4 dimensions: first language switching tendencies (L1S: 9.45 ± 1.43), second language switching tendencies (L2S: 7.45 ± 1.85), contextual switches (CS: 7.15 ± 1.53), and unintended switches (US: 5.85 ±1.73). The higher the score in each dimension, the higher their language switching rate in the daily life.

2.2 Language switching materials

We used a picture-naming paradigm as the language switching task. The stimuli, 72 black-and-white line-drawing pictures (15cm × 15 cm), were selected from the Snodgrass and Vanderwart's picture database (1980). The pictures were standardized by Zhang and Yang (2003). Specifically, the Chinese names of all pictures were two-character words whose English equivalents were either one- or two-syllable words with 3-6 letters. Since English lexical frequency is assessed in English-dominated countries, some items with high lexical frequency appear less frequently for Chinese people, so we selected the items whose familiarity on English and Chinese were matched. Thirty-five Chinese (L1)–English (L2) bilinguals with an intermediate L2 proficiency rated the familiarity of these words (5-point scale; 1 = very unfamiliar, 5 = very familiar"). No significant differences were found between the L1 and L2 (L1: 4.85 ± .08, L2:

4.84 ± .12, $t(34) = .69$, $p = .76$). Then the 72 pictures were equally randomized into the three stimulation sessions to eliminate practice effects. Paired sample T-tests showed no proficiency differences between the L1 and L2 picture names in each session (see Table 2). A repeated measures ANOVA indicated no differences between the three sessions either ($F(2, 46) = .36$, $p = .64$).

Table 2. Proficiency of the experimental materials

	L1	L2	*t*	*p*
First session	4.83 (.15)	4.86 (.08)	.86	0.32
Second session	4.86 (.07)	4.85 (.08)	-.24	0.21
Third session	4.86 (.10)	4.84 (.10)	-1.04	0.26

2.3 Procedure

Transcranial direct stimulations (tDCS)

The experimental procedure of our study is presented in Figure 1. As shown in Figure 1, three different stimulation sessions were conducted: anodal (A-tDCS), cathodal (C-tDCS) and sham (S-tDCS) stimulation. The order of stimulation was fully counterbalanced across participants. During the tDCS, participants were asked to sit quietly and do nothing. The A-tDCS can depolarize cells and accelerate the transmission of information between neurons. On the contrary, the C-tDCS hyperpolarizes cells, thus slowing down the transmission of information between neurons (Stagg & Nitsche, 2011). The S-tDCS, used as a control stimulation, gives a shorter stimulation (30s), which makes the subjects feel the same subjective experience as during the real stimulation. It does not affect the cell membrane potential or the transmission of information between neurons (Avenanti, Paracampo, Annella, Tidoni, & Aglioti, 2017; Brunoni et al., 2012; Hill, Fitzgerald, & Hoy, 2016; Meinzer et al., 2012). Hence, the A-tDCS may enhance participants' performance, while the C-tDCS weakens it. Performance during S-tDCS should be somewhere between the A-tDCS and C-tDCS.

We applied tDCS (1 mA) over the rDLPFC for 25 minutes per session via two electrodes (See Figure 1). To minimise skin irritation, we had stimulation electrodes surrounded by a flat sponge which was soaked in an isotonic NaCl solution and was coated with Aqua Sonic TM ultrasound transmission gel. During the A-tDCS and C-tDCS sessions, one constant current stimulator

(ActivaDose Ⅱ Iontophoresis Delivery Unit, USA) was placed halfway between the EEG electrode sites for F4 of the 10-20 EEG system, and was fixed by a rubber belt. The other was affixed to the right shoulder with a skin-friendly cello type. For the S-tDCS, the manipulation was the same but tDCS was turned off after 60 seconds and turned on for 60 seconds before the end of stimulation. There was a ramping period of 10 seconds at the start and the end of each tDCS condition and the study design was single-blinded (i.e., participants were kept naïve about when and which tDCS was delivered). A questionnaire was administrated at the end of each session to assess potential tDCS side effects (Fertonani, Rosini, Cotelli, Rossini, & Miniussi, 2010).

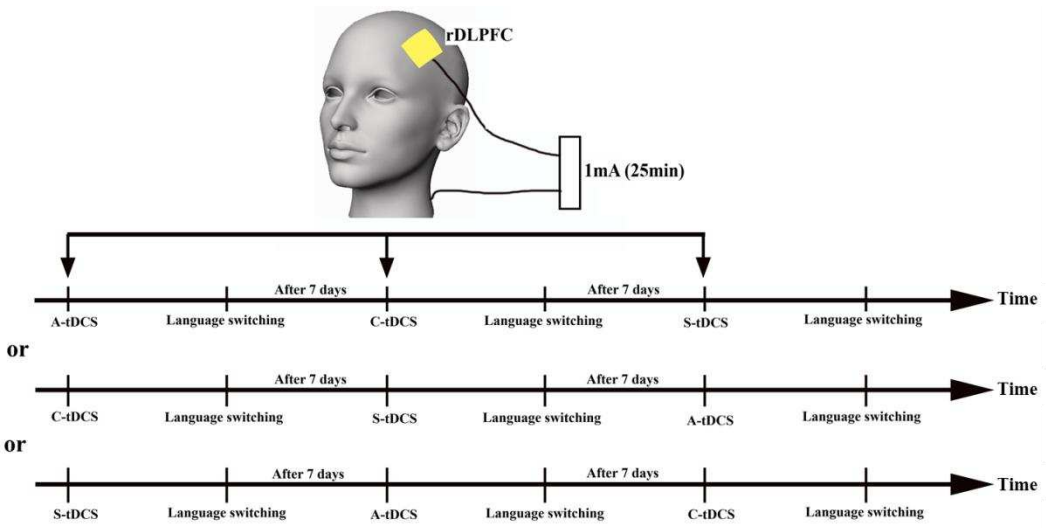

Figure 1. Experimental procedure. Prior to each language switching task, participants received a type of stimulation. The three stimulation sessions (A-tDCS, C-tDCS and S-tDCS) and language switching tasks were counterbalanced across participants, and each session was separated by 7 days. For example, participant A received the anodal stimulation in day 1 and completed a language switching task. Seven days later, A received the cathodal stimulation and completed the second language switching task. And after another 7 days, the sham stimulation was delivered to him followed by the last language switching task. The stimuli used in the three language switching tasks were different, and counterbalanced across participants. Other participants received stimulations and finished language switching tasks in different orders.

Voluntary language switching procedure

After receiving the tDCS stimulation corresponding to each session, participants were familiarized with the stimuli by showing each picture with the corresponding words in L1 and L2. This familiarization was used to reduce errors in recognizing the pictures or

using the wrong word. Then they began the formal experiment. Stimuli were presented at the center of a 17-inch computer screen with 1024 × 768 pixel resolution. In the beginning, a fixation appeared for 250 ms, instructing participants to concentrate on the screen, followed by a blank screen for 500 ms. Then the picture stimulus was presented. Participants were instructed that they could use either L1 or L2 to name and to just say the name that first comes to mind. Both naming speed and accuracy were emphasized. The picture disappears immediately after naming it or after 2000 ms. At the end, a blank screen for 1000 ms appeared before the next trial started.

There were 5 blocks per session. Each block consisted of 96 experimental pictures and 2 practice pictures. All stimuli were presented pseudo-randomly. The same picture appeared twice in each block. Prior to the formal experiment, participants performed 12 practice trials and their response times were recorded by a PSTSR-BOX connected to a microphone. All responses were recorded by a voice recorder. The responses were then classified by two experimenters as belonging to one of four trials types (L1 repeat, L2 repeat, L1 switch, L2 switch).

2.4 Electrophysiological recording

Electrophysiological data were recorded by a set of 64 electrodes from eegmagine (ANT Neuro) according to the extended 10-20 positioning system. The sampling rate was 1 kHz and the signal was referenced online to the CPZ electrode. The electrodes M1 and M2 were separately placed on the left and right mastoids. Impedances were kept below 5 kΩ. In offline processing we reduced the sampling rate to 500 Hz. The offline data was referenced to the average of M1 and M2. EEG activity was filtered online with a bandpass between 0.1 and 100 Hz and refiltered offline with a 30 Hz, low-pass, zero-phase shift digital filter. Ocular artifact reduction was performed through ICA component rejection by using EEGLAB (Delorm & Makeig, 2004). Other movement artifacts were identified by visual inspection and manually removed.

The continuous recoding was segmented into stimulus-locked -100 to 600 ms segments to dissociate each step of language switching. Correspondingly, the epochs were referenced to the 100 ms pre-stimulus baseline. Signals exceeding ±80 μV in any given epoch were automatically discarded.

2.5 Behavioral data analysis

We identified five types of incorrect responses as follows: a) no or late response (e.g., no latency or latency above 1500ms), b) wrong word (e.g., uttering 'house' for the picture of a flower), c) hesitation, d) combination of both languages, e) recording failures. All incorrect responses, the first two trials in each block and data from naming latencies beyond M ± 3SD per participants were

removed. Considering that it's impossible for participants to utter the word within 250 ms, trials with naming latencies below 250 ms were removed too. For naming latency, a three-way repeated-measures ANOVA was run with three within-subject factors: tDCS Session (A-tDCS, C-tDCS, S-tDCS), Language (L1, L2), and Language Sequence (repeat, switch).

2.6 Stimulation of tDCS questionnaire

A translated and adapted version of the standardized questionnaire (Fertonani et al., 2010) was conducted to assess possible stimulation-induced perceived sensations. Items in this questionnaire were distinct sensation and possible tDCS side effects (Poreisz, Boros, Antal, & Paulus, 2007). The intensity of each sensation item was rated on a 5-point scale (none = "1", strong = "5"). After each session, the participants were asked to rate the intensity of each sensation, the degree of sensational influence on their performance and the period of the sensational influence (beginning = "1", middle = "2", end = "3" of the experiment). To test whether there was a difference among the three stimulations, one-way ANOVAs were conducted for each sensation item. The result showed that there was no difference among the three conditions (see Table 3).

Table 3. Self-rating of each sensation item

Items	A- tDCS	C- tDCS	S- tDCS	*F*	*p*
Itchiness	1.77 (.97)	1.64(.79)	1.64 (.79)	.54	.54
Pain	2.09 (1.02)	2.32 (1.00)	2.09 (1.11)	.74	.74
Burning	1.45 (.67)	1.50 (.80)	1.32 (.57)	.88	.88
Warmth/heath	1.32 (.57)	1.41 (.59)	1.32 (.57)	.31	.31
Pinching	1.41 (0.73)	1.45 (.60)	1.32 (.57)	.24	.24
Iron taste	1.00 (.00)	1.05 (.21)	1.05 (.21)	.23	.23
Fatigue	1.59 (.73)	1.50 (.67)	1.59 (.80)	.40	.40
Effect on performance	1.68 (.57)	1.45 (.60)	1.41 (.67)	.31	.31
Start	1.55 (.74)	1.82 (.80)	1.45 (.67)	.11	.11
End	1.68 (.78)	1.73 (.70)	1.45 (.60)	.525	.53

2.7 Event-related brain potential analysis

Our analyses focused on a naming picture-locked period during voluntary language switching. For this period, we analyzed the N2 and LPC for which the time-windows were 200-350 ms and 400-600 ms respectively (Jackson, Swainsion, Cunnington, & Jackson, 2001; Liu et al., 2016; Martin, Strijkers, Santesteban, Escera, Hartsuiker, & Costa, 2013; Verhoef, Roeiots, & Chwilla, 2009; 2010). Greenhouse-Geisser corrections were applied for sphericity violations. Based on visual inspection of the current data and previous language switching studies, we focused on the analysis of the N2 over three regions: frontal: F3, F1, FZ, F2, F4; frontal-central: FC3, FC1, FCZ, FC2, FC4; and central: C3, C1, CZ, C2, C4. Meanwhile, we focused on the analysis of the LPC over five regions: frontal: F3, F1, FZ, F2, F4; frontal-central: FC3, FC1, FCZ, FC2, FC4; and central: C3, C1, CZ, C2, C4; central-parietal: CP3, CP1, CPZ, CP2, CP4; and parietal: P3, P1, PZ, P2, P4.

Data from the first two trials of each block, incorrect response trials, and any trials contaminated by artifacts were removed from the analyses, which led to 3.72% of rejected trials. The average number of trials per condition was 115.53 (SD = 2.700), which were used to for the ANOVA analyses and ERP figures. To minimize the experiment-wise Type-I error rate, we chose a three-way repeated-measures ANOVA on the mean amplitudes of N2 and LPC across milliseconds within the time-window and sensors for the N2/LPC (Luck & Gaspelin, 2017): Session (A-tDCS, C-tDCS, S-tDCS), Language (L1, L2), and Language Sequence (repeat, switch). When appropriate, the estimated Greenhouse-Geisser coefficient ε was used to correct for violations of the sphericity assumption (Geisser & Greenhouse, 1958). All reported p-values are based on corrected degrees of freedom with Bonferroni corrections, but to aid the reader in interpreting our statistical design, the stated degrees of freedom are uncorrected.

3. Results

The analysis of the behavioral and ERP data aimed to establish whether we could i) change voluntary language switching efficiency by enhancing or weakening inhibition, ii) determine how bilinguals switch languages in the S-tDCS session.

3.1 Behavioral results

a) Accuracy

Participants performed the task efficiently, with high average accuracy in all three sessions (A-tDCS session, 98.99 ± 1.37; C-tDCS session, 98.91 ± 1.66; S-tDCS session, 99.15 ± 1.03). There were no main effects or interactions for accuracy.

b) Switching frequency

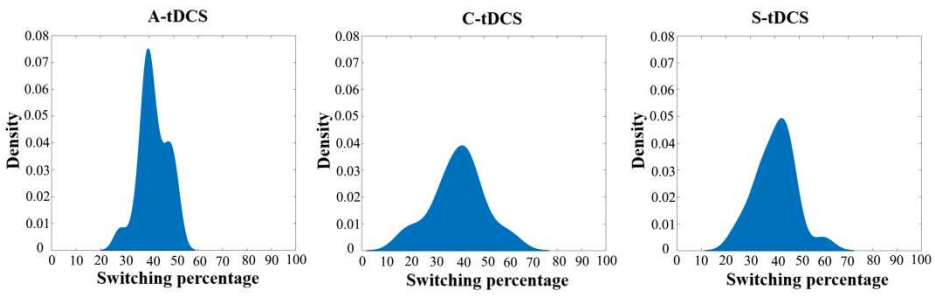

Figure 2. Density plots showing the distribution of the switching percentages across participants in each session.

Switching frequency was calculated as the number of stimuli belonging to a specific trial type divided by the total number of stimuli. Overall switching frequency did not differ between the three t-DCS sessions. Average switching frequency in the A-tDCS session was 41.64 (5.69), 39.55 (10.67) in the C-tDCS session, and 40.12 (7.95) in the S-tDCS session (see Figure 2). In the A-tDCS session, over 80% of the participants switched between 25% to 55% of the trials (see Figure 2, left panel). In the C-tDCS session, over 80% of the participants switched between 10% to 70% (see Figure 2, middle panel). In the S-tDCS session, over 80% of the participants switched between 15% to 65% (see Figure 2, right panel).

We also calculated average switching frequency for each language per tDCS session (A-tDCS session: 20.70 ± 2.95 for L1, 20.98 ± 2.95 for L2; C-tDCS session: 19.11 ± 4.92 for L1, 19.21 ± 4.70 for L2; S-tDCS session: 19.54 ± 3.30 for L1, 19.69 ± 4.70 for L2). To further reveal the impact of tDCS on switching frequency, a separate by-session analysis was conducted. The three sessions all showed a higher percentage of L2 repeat trials (33.65 ± 7.04) than L1 repeat trials (21.84 ± 5.23) ($F(1, 19) = 23.41$, $p < .001$, $\eta^2_p = .55$, $F(1, 19) = 27.34$, $p < .001$, $\eta^2_p = .59$, $F(1, 19) = 35.15$, $p < .001$, $\eta^2_p = .65$).

Besides, we compared how often participants used each language in each session. Paired samples T-tests showed that L2 was more often used than L1 in each session (A-tDCS session: 42.55 ± 5.33 for L1, 54.63 ± 5.62 for L2, $t(71) = -3.80$, $p < 0.001$; C-tDCS session:41.98 ± 5.84 for L1, 55.01 ±5.35 for L2, $t(71) = -3.13$, $p = 0.03$; S-tDCS session: 42.30 ± 4.80 for L1, 55.17 ± 5.12 for L2, $t(71) = -2.98$, $p = 0.04$).

In short, all three sessions showed more L2 than L1 responses. In all sessions, there were more L2 repeat trials than L1 repeat trials.

c) Latency

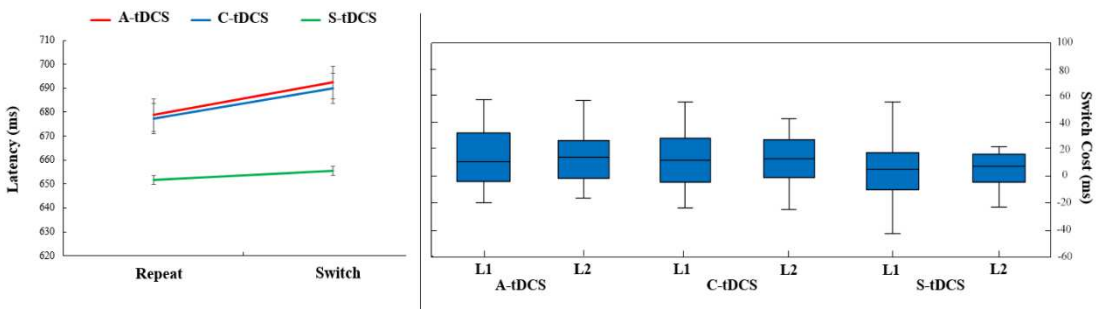

Figure 3. Mean naming latencies and switch costs (and SD) of each session. Left: Overall latencies per session. Right: Magnitude of the language switch costs per session.

A three-way repeated-measures ANOVA was run with three within-subject factors: tDCS Session (A-tDCS, C-tDCS, S-tDCS), Language (L1, L2), and Language Sequence (repeat, switch). Bilinguals named the pictures more slowly in the A-tDCS session (686 ± 15 ms) and the C-tDCS session (684 ± 12 ms) compared to the S-tDCS session (653 ± 14 ms), as indicated by a significant main effect of Session ($F(2, 19) = 5.01$, $p = .01$, $\eta^2_p = .21$; A-tDCS vs. S-tDCS: $t(19) = 2.58$, $p = 0.02$; C-tDCS vs. S-tDCS: $t(19) = 2.95$, $p = .01$). Furthermore, responses were faster in L2 (663 ± 11 ms) than in L1 (685 ± 13 ms), as indicated by a significant main effect of Language ($F(1,19) = 23.78$, $p < .001$, $\eta^2_p = .56$). Overall switch costs were highly robust, as indicated by a main effect of Language Sequence ($F(1,19) = 17.44$, $p < .001$, $\eta^2_p = .48$), such that switch trials (679 ± 12 ms) elicited longer naming latencies than repeat trials (669 ± 12 ms), suggesting that top-down control processes may be involved in voluntary switching. More importantly, the interaction between Session and Language Sequence was significant ($F(2, 38) = 3.46$, $p = .04$, $\eta^2_p = .15$). Table 4 shows the details about the follow-up analyses. i) From the perspective of Language sequence, the responses were slower on switch trials compared with repeat trials in both the A-tDCS session (switch trials: 692 ± 15 ms, repeat trials: 679 ± 14 ms) and the C-tDCS session (switch trials: 690 ± 12 ms, repeat trials: 677± 12 ms), indicating that there were switch costs in these two sessions. In contrast, naming latencies did not differ between repeat (652 ± 64 ms) and switch trials (655 ± 63 ms) in the S-tDCS session, suggesting there was no switch cost. ii) From the perspective of session, the naming latencies of repeat trials in the S-tDCS session (652 ± 64ms) were shorter than those in the A-tDCS session (679 ± 64 ms), but the repeat trials in the S-tDCS (652 ± 64ms) did not differ from those in the C-tDCS (677 ± 52 ms). The naming latencies of switch trials in the S-tDCS session (655 ± 63 ms) were shorter than those in the A-tDCS session (692 ± 68 ms), and the C-tDCS session (690 ± 54 ms). These findings suggest that anodal and cathodal stimulation may slow the naming response, in particular in switch trials, and produce obvious switch costs. These findings suggest that tDCS could affect overall naming latencies as well as switch costs in a voluntary switching task.

Table 4. Simple analysis for the interactions between Session × Language Sequence in naming latencies.

	Comparisons	*F*	*p*	η_p^2
Session	A-tDCS: Switch > Repeat	32.49	< .001	.49
	C-tDCS: Switch > Repeat	27.44	< .001	.50
Language sequence	Repeat: A-tDCS > S-tDCS	20.11	.04	40
	Switch: A-tDCS > S-tDCS	25.32	.006	.50
	Switch: C-tDCS > S-tDCS	24.61	.01	.47

3.2 ERP results

a) N2 *(200-350ms)*

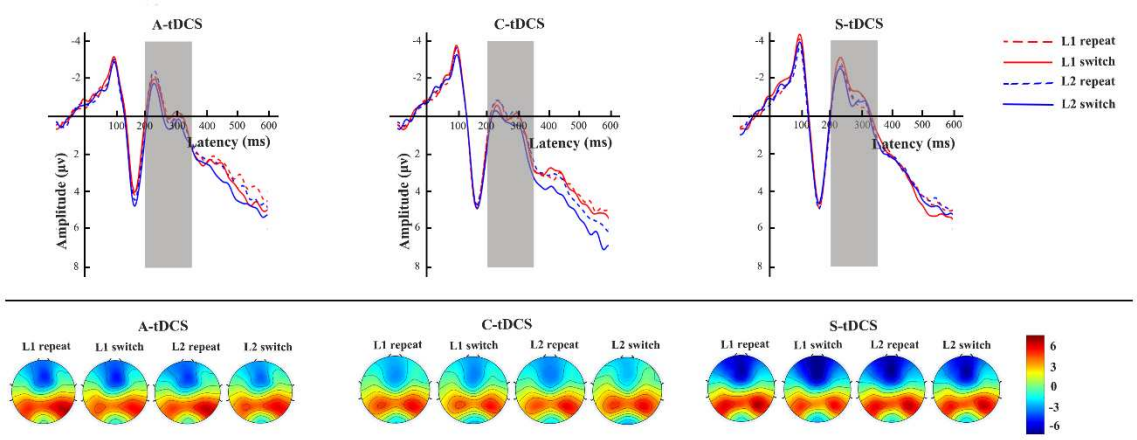

Figure 4. The top panel shows N2 grand average waveforms that time-locked to the onset of picture naming for the two Language Sequences (Repeat, Switch), per language (L1, L2) in each session over 15 sensors. The yellow shading represents the early (200-350 ms) time window. Bottom panels show scalp distributions for the two levels of Language Sequence (Repeat, Switch), per language (L1, L2) in each session, obtained by interpolation from 64 sites.

In Figure 4, N2 grand average waveforms for the two levels of Language and Language sequence are displayed separately for A-tDCS, C-tDCS and S-tDCS sessions. There were no main effects or interactions for the N2 component. That is, the N2 component did not differ between switch and repeat trials, L1 and L2, or between the three sessions.

b) LPC (400-600ms)

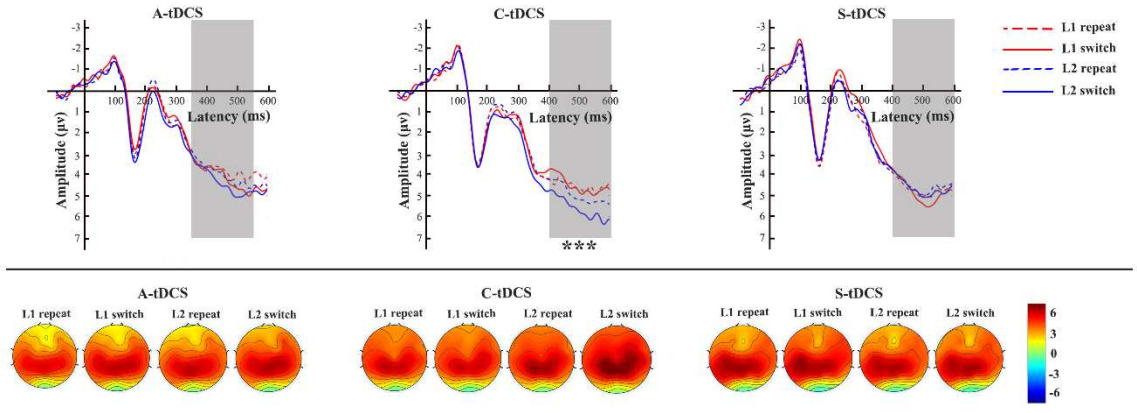

Figure 5. The top panel shows LPC grand average waveforms that time-locked to the onset of picture naming for the two Language Sequences (Repeat, Switch), per language (L1, L2) in each session over 25 sensors. The yellow and gray shading respectively represent the early (200-350 ms) and late (400-600 ms) time windows. Bottom panels show scalp distributions for the two levels of Language Sequence (Repeat, Switch), per language (L1, L2) in each session, obtained by interpolation from 64 sites. Note: *** indicates $p < 0.001$.

In Figure 5, the LPC grand average waveforms for the two levels of Language and Language sequence are displayed separately for A-tDCS, C-tDCS and S-tDCS sessions. A three-way repeated-measures ANOVA was conducted with three within-subject factors: tDCS Session (A-tDCS, C-tDCS, S-tDCS), Language (L1, L2), and Language Sequence (repeat, switch). It revealed a main effect of Language Sequence ($F(1, 19) = 9.66$, $p = .04$, $\eta^2_p = .20$), with a larger LPC in switch trials (4.75 ± 0.48μV) than repeat trials (4.46 ± 0.46μV). The three-way interaction of tDCS Session, Language and Language Sequence reached significance ($F(2, 38) = 8.97$, $p = .04$, $\eta^2_p = .17$). Further analyses showed that L2 switch trials (5.64 ± 0.71μV) elicited a larger LPC than L1 switch trials (4.43 ± 0.65μV) in the C-tDCS session ($F(1, 19) = 15.22$, $p < .001$, $\eta^2_p = .14$), but not in the A-tDCS (L1 switch trials : 4.38 ± 3.16 μV, L2 switch trials : 4.67 ± 2.92 μV, $F(1, 19) = .43$, $p = .52$, $\eta^2_p = .02$) or in the S-tDCS session (L1 switch trials : 4.75 ± 3.05 μV, L2 switch trials : 4.55 ± 2.49μV, $F(1, 19) = .55$, $p = .65$, $\eta^2_p = .04$).

To summarize, first, there were significant behavioural switch costs in the A-tDCS and C-tDCS sessions but there was no switch cost in the S-tDCS session. Participants also named switch trials more slowly in the A-tDCS and C-tDCS sessions than in the S-tDCS

session. Further, the C-tDCS showed larger a LPC when switching to L2 than to L1, while neither the A-tDCS session nor the S-tDCS session showed these LPC differences. These findings suggest that changing inhibition did not improve language switching. Second, the S-tDCS did not elicit any behavioural or neural differences between conditions (L1/L2 repeat, L1/L2 switch).

4. Discussion

The current study applied tDCS over the rDLPFC (an area responsible for inhibitory control) to reveal the secret of voluntary language switching: whether and how inhibitory control is involved during voluntary language switching. The following main points were found: i) the A-tDCS and C-tDCS sessions showed a behavioural switch cost while the S-tDCS session did not; and the naming latencies of switch trials in the A-tDCS and C-tDCS sessions were longer than in the S-tDCS session; ii) only the cathodal stimulation showed a language switching effect in ERPs, i.e., switching to L2 elicited a larger LPC than switching to L1.

Together, these finding show that during unhindered voluntary language switching (i.e., in the sham condition), Chinese-English unbalanced bilinguals showed no behavioral or neural switch cost. In contrast, when inhibitory control was manipulated through A-tDCS or C-tDCS, behavioural and (in the case of C-tDCS) neural switch costs were observed during voluntary language switching. Thus, in contrast to previous work showing that tDCS facilitated cued language switching (Li et al., 2018), the current findings suggest that inhibitory control is not necessary beneficial for voluntary switching and may lead to switch costs. One possible interpretation is that inhibitory control interferes with bottom-up lexical access mechanisms that may be used to freely select the language during voluntary switching.

4.1 The effect of tDCS on overt naming behavior

First, the unbalanced bilinguals were found to name more items in their L2 than L1. Responses were also faster in L2 than L1. Reversed dominance effects for unbalanced bilinguals, with faster L2 responses, have been found in previous voluntary language switching studies testing unbalanced Spanish-English bilinguals (Gollan & Ferreira, 2009). One possible interpretation is that unbalanced bilinguals proactively suppressed their dominant language to enable the use of the weaker L2 in a free dual-language context. However, it should be noted that these language effects were not affected by the tDCS session, suggesting that they were not affected by our manipulation of the rDLPFC.

Unexpectedly, unbalanced bilinguals showed larger switch costs and slower responses on switch trials in the A-tDCS and C-tDCS sessions than in the sham session. These findings suggest that both the A-tDCS and C-tDCS degrade performance during

voluntary language switching. According to the principle of tDCS (Stagg & Nitsche, 2011), A-tDCS increases the discharging rhythm between cortex and increases the excitability of the cortex, thus improving the inhibitory control function over the rDLPFC, while C-tDCS decreases this function. However, previous studies have demonstrated that C-tDCS does not always degrade cognitive performance (Heinen, Sagliano, Candini, Husain, Cappelletti, & Zokaei, 2016; Pope & Miall, 2012; Weiss & Lavidor, 2012). Consequently, previous research has focused mainly on the question whether tDCS is an effective method without dissociating the impact of different types of stimulation. We thus hypothesized that if inhibitory control is involved during voluntary switching, applying tDCS over the rDLPFC would *change* performance. Instead, the worsened performance suggests that the changes in inhibitory control interfere with the typically used mechanisms in language switching. So, what is this mechanism of voluntary language switching?

Lexical access has been suggested as one of the mechanisms underlying voluntary language choice and switching (de Bruin et al., 2018; Gollan & Ferreira, 2009; Gollan et al., 2014; Kleinman & Gollan, 2016; Seo et al., 2018). The naming latencies in the S-tDCS session, showing no switch cost in the L1 or L2, suggest that lexical access may have been involved. Because L1 and L2 items were matched on familiarity unbalanced bilinguals may freely, like balanced bilinguals, select any language available. Some previous studies also confirmed that lexical-accessibility-driven bottom-up mechanism play an important role in voluntary language switching, which is reflected by the scarce of switch costs (Blanco-Elorrieta & Pylkkänen, 2017; Kleinman & Gollan, 2016).

In addition to lexical effects, morphosyntactic information (e.g., sub-lexical phonological and articulatory levels) can also impact switch costs (Gullifer, Kroll, & Dussias, 2013; Gollan, Kleinman, & Wierenga, 2014; Poulisse, 1999; Poulisse & Bongaerts, 1994). For example, Gollan et al., 2014 required bilinguals to read aloud paragraphs written in either a single language or in a mixture of Spanish and English. Behavioral data showed more cross-language errors for function words than content words. Eye movement data showed that longer fixations on function words in the other language were connected with more intrusion errors of function words, but not content words. These results suggest that switch costs resulted from both lexical (i.e., cross-language errors) and sublexical (i.e., accent errors) levels. In the current study, probably due to the parallel familiarity of 72 Chinse and English lexical and sublexical items, unbalanced bilinguals can easily access any language, resulting in the absence of switch costs and neural differences between experimental conditions. The changed inhibition could have hindered the activation of lexical and sublexical processes, resulting in worsened language switching performance. Specifically, the changed inhibitory control may impose an additional cognitive burden on voluntary language switching and interfere with the processes of lexical and sublexical access. That is, unbalanced bilinguals may

have direct access to words in one language, but may hesitate and inappropriately inhibit one of the languages due to changed inhibitory control. This extra inhibition may have led to longer naming latencies of switch trials in the A-tDCS session and larger switch costs in the A-tCDS and C-tDCS sessions compared to the S-tDCS session.

4.2 The effect of tDCS on event-related potentials

First, we expected a larger N2 for switch than repeat trials based on previous work showing that N2 plays an important role in conflict monitoring during attentional processes (Bush, Luu, & Posner, 2000However, we did not find any N2 difference between switch trials and repeat trials across the three sessions. If bilinguals freely use a language to name the picture, there might not be competition in selecting the appropriate language task schema during voluntary language switching. Thus, the L1 and L2 task schemas might not have elicited sufficient conflict for an ERP effect to arise at this early time window. Another possibility is that although anodal and cathodal stimulations changed the bilinguals' inhibitory control, the bilinguals still resorted to other mechanisms to achieve voluntary language switching. We thus did not observe differences in N2 which reflect conflict detection and monitoring (Verhoef, Roelofs, & Chwilla, 2009, 2010; Bachman & Bernat, 2018; Başar-Eroglu et al., 1992; Dippel et al., 2016; Demiralp et al., 2001; Huster et al., 2013).

Second, the A-tDCS and S-tDCS sessions did not show any differences in the LPC, while the C-tDCS session displayed larger LPC for switching to L2 compared to switching to L1. There are two possibilities. On the one hand, if voluntary language switching did not involve inhibition, even in the C-tDCS session, L1 repeat/switch and L2 repeat/switch trials should have shown similar LPC patterns. Instead, we found that after unbalanced bilinguals underwent cathodal stimulation, the LPC showed differences between trial types. It may be the case that cathodal stimulation also worked on other brain areas (e.g., supplementary motor area, SMA), which potentially altered the bilinguals' speech planning. The stimulation range of tDCS was large (5 cm *5 cm) and consequently, in addition to changing the rDLPFC, it also may have stimulated the SMA. This brain area is involved in the motor planning of speech (Bohland & Guenther, 2006; Wise, Chollet, Hadar, Friston, Hoffner, & Frackowiak, 1991). For example, Bohland and Guenther (2006) used a Go/No-go task to explore the cortical and subcortical regions involved in organizing and enacting sequences of simple speech sounds. Their results showed that the SMA and pre-SMA were more activated during the Go compared to the No-go condition. They proposed that this may have been because participants were allowed to articulate during the Go condition, suggesting that the SMA was related to the initialization of a speech plan, control of the articulators, and hearing one’s own voice. In our study, cathodal

stimulation may have weakened the excitement of SMA, and have made it more difficult to retrieve L2 words. Therefore, switching to L2 may have elicited a larger LPC related to lexical information integration (Berkes et al., 2018) than switching to L1.

On the other hand, recent language switching studies propose that LPC represents inhibition of competing lexical items, in particular that switching to L2 can elicit larger LPC than switching to L1 (Liu et al., 2018). Interestingly, the current study found that the cathodal stimulation elicited larger LPC when switching to L2 compared to L1. This could illuminate that cathodal stimulation weakened the excitement of SMA, making the retrieval of L2 items more difficult. As a consequence, switching to L2 may have experienced more L1 interference, which needs to be inhibited. This may be why LPC effects were observed. Of course, this generalization effect of tDCS also occurs on anodal stimulation, but probably due to enhanced inhibition, it may have been easier to inhibit the cross-language interference, which may be why few neural differences were observed in the A-tDCS session.

In brief, both A-tDCS and C-tDCS over the rDLPFC interfered with voluntary language switching, leading to switch costs in these conditions that were not observed in natural voluntary language switching without alteration in the rDLPFC. Therefore, bilinguals may be able to switch languages without inhibitory control. Furthermore, our previous cued language switching studies (Li et al., 2018) found that the alteration of the rDLPFC responsible for inhibitory control via tDCS makes participants in the cued language switching naming faster and reduces switching costs This demonstrates that inhibitory control plays an important role in cued language switching. We may not have observed facilitatory tDCS effects on voluntary language switching because the latter adopts more bottom-up mechanisms. Future studies may attempt to use tDCS to stimulate brain regions related to lexical and sublexical accessibility, and to further investigate the effects of changes in excitability of the brain regions on language switching.

References

Avenanti, A., Paracampo, R., Annella, L., Tidoni, E., & Aglioti, S. M. (2017). Boosting and decreasing action prediction abilities through excitatory and inhibitory tDCS of inferior frontal cortex. *Cerebral Cortex, 28*(4), 1282-1296.

Allan, D. (2006). Oxford Placement test 1: Audio CD. Oxford, UK.: Oxford University Press.

Bachman, M. D., & Bernat, E. M. (2018). Independent contributions of theta and delta time-frequency activity to the visual oddball P3b. *International Journal of Psychophysiology*, *128*, 70-80.

Bakker, I., Takashima, A., van Hell, J. G., Janzen, G., & McQueen, J. M. (2015). Tracking lexical consolidation with ERPs: Lexical and semantic-priming effects on N400 and LPC responses to newly-learned words. *Neuropsychologia, 79*, 33-41.

Başar-Eroglu, C., Başar, E., Demiralp, T., & Schürmann, M. (1992). P300-response: possible psychophysiological correlates in delta and theta frequency channels. A review. *International Journal of Psychophysiology*, *13*(2), 161-179.

Başar, E., Başar-Eroğlu, C., Karakaş, S., & Schürmann, M. (1999). Are cognitive processes manifested in event-related gamma, alpha, theta and delta oscillations in the EEG?. *Neuroscience letters, 259*(3), 165-168.

Berkes, M., Friesen, D. C., & Bialystok, E. (2018). Cultural context as a biasing factor for language activation in bilinguals. *Language, Cognition and Neuroscience*, 1-17.

Blanco-Elorrieta, E., & Pylkkänen, L. (2017). Bilingual language switching in the lab vs. in the wild: The spatio-temporal dynamics of adaptive language control. *Journal of Neuroscience*, 0553-17.

Bohland, J. W., & Guenther, F. H. (2006). An fMRI investigation of syllable sequence production. *Neuroimage, 32*(2), 821-841.

Brunoni, A. R., Nitsche, M. A., Bolognini, N., Bikson, M., Wagner, T., Merabet, L., ... & Ferrucci, R. (2012). Clinical research with transcranial direct current stimulation (tDCS): challenges and future directions. *Brain stimulation, 5*(3), 175-195.

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in cognitive sciences*, *4*(6), 215-222.

Cai, Q., & Brysbaert, M. (2010). SUBTLEX-CH: Chinese word and character frequencies based on film subtitles. *PloS one*, *5*(6), e10729.

Christoffels, I., Firk, C., & Schiller, N. O. (2007). Bilingual lan- guage control: An event-related brain potential study. *Brain Research*, *1147*, 192–208.

Costa, A., & Santesteban, M. (2004). Lexical access in bilingual speech production: Evidence from language switch- ing in highly proficient bilinguals and L2 learners. *Journal of Memory and Language*, *50*, 491–511.

de Bruin, A., Samuel, A. G., & Duñabeitia, J. A. (2018). Voluntary language switching: When and why do bilinguals switch between their languages?. *Journal of Memory and Language*, *103*, 28-43.

Declerck, M., & Philipp, A. M. (2015). A review of control processes and their locus in language switching. *Psychonomic Bulletin & Review*, *22*, 1630–1645.

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of neuroscience methods, 134*(1), 9-21.

Dippel, G., Chmielewski, W., Mückschel, M., & Beste, C. (2016). Response mode-dependent differences in neurofunctional networks

during response inhibition: an EEG-beamforming study. *Brain Structure and Function*, *221*(8), 4091-4101.

Elke, S. , & Wiebe, S. A. (2017). Proactive control in early and middle childhood: an ERP study. *Developmental Cognitive Neuroscience, 26*, 28-38.

Fertonani, A., Rosini, S., Cotelli, M., Rossini, P. M., & Miniussi, C. (2010). Naming facilitation induced by transcranial direct current stimulation. *Behavioural brain research, 208*(2), 311-318.

Geisser, S., & Greenhouse, S. W. (1958). An extension of box's results on the use of the $ F $ distribution in multivariate analysis. *The Annals of Mathematical Statistics, 29*(3), 885-891.

Gajewski, P. D. , Stoerig, P. , & Falkenstein, M. (2008). ERP—correlates of response selection in a response conflict paradigm. *Brain Research, 1189*, 127-134.

Geisser, S., & Greenhouse, S. W. (1958). An extension of boxes results on the use of the F distribution in multivariate-analysis. *Annals of Mathematical Statistics, 29*(3), 885–891.

Gollan, T. H., & Ferreira, V. S. (2009). Should I stay or should I switch? A cost–benefit analysis of voluntary language switching in young and aging bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*(3), 640.

Gollan, T. H., Kleinman, D., & Wierenga, C. E. (2014). What's easier: Doing what you want, or being told what to do? Cued versus voluntary language and task switching. *Journal of Experimental Psychology: General*, *143*(6), 2167.

Gollan, T. H., Schotter, E. R., Gomez, J., Murillo, M., & Rayner, K. (2014). Multiple levels of bilingual language control evidence from language intrusions in reading aloud. *Psychological Science*, *25*(2), 585-595.

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition, 1*, 67–81.

Gross, M., & Kaushanskaya, M. (2015). Voluntary language switching in English-Spanish bilingual children. *Journal of Cognitive Psychology, 27*, 992–1013.

Gullifer, J. W., Kroll, J. F., & Dussias, P. E. (2013). When language switching has no apparent cost: lexical access in sentence context. *Frontiers in Psychology,4*, 278.

Heinen, K., Sagliano, L., Candini, M., Husain, M., Cappelletti, M., & Zokaei, N. (2016). Cathodal transcranial direct current stimulation over posterior parietal cortex enhances distinct aspects of visual working memory. *Neuropsychologia*, *87*, 35-42.

Hill, A. T., Fitzgerald, P. B., & Hoy, K. E. (2016). Effects of anodal transcranial direct current stimulation on working memory: a systematic review and meta-analysis of findings from healthy and neuropsychiatric populations. *Brain stimulation, 9*(2), 197-208.

Huster, R. J., Enriquez-Geppert, S., Lavallee, C. F., Falkenstein, M., & Herrmann, C. S. (2013). Electroencephalography of response inhibition tasks: functional networks and cognitive contributions. *International journal of psychophysiology*, *87*(3), 217-233.

Lemhöfer, K., & Broersma, M. (2012). Introducing LexTALE: A quick and valid lexical test for advanced learners of English. *Behavior research methods, 44*(2), 325-343.

Li, B., Liu, H., Pérez, A., & Xie, N. (2018). Cathodal transcranial direct current stimulation over right dorsolateral prefrontal cortex improves language control during language switching. *Behavioural brain research*, *351*, 34-41.

Liu, H., Liang, L., Dunlap, S., Fan, N., & Chen, B. (2016). The effect of domain-general inhibition-related training on language switching: An ERP study. *Cognition, 146*, 264-276.

Liu, H., Xie, N., Zhang, M., Gao, X., Dunlap, S., & Chen, B. (2018). The electrophysiological mechanism of joint language switching: Evidence from simultaneous production and comprehension. *Journal of Neurolinguistics, 45*, 45-59.

Luck, S. J., & Gaspelin, N. (2017). How to get statistically significant effects in any ERP experiment (and why you shouldn't). *Psychophysiology, 54*(1), 146-157.

Kleinman, D., & Gollan, T. H. (2016). Speaking two languages for the price of one: Bypassing language control mechanisms via accessibility-driven switches. *Psychological science*, *27*(5), 700-714.

Kleinman, D., & Gollan, T. H. (2018). Inhibition accumulates over time at multiple processing levels in bilingual language control. *Cognition, 173*, 115–132.

Kimberg, D.Y., Aguirre, G.K., and D'Esposito, M. (2000). Modulation of task-related neural activity in task-switching: an fMRI study. *Cognitive Brain Research, 10*, 189–196.

Matsumoto, A., Iidaka, T., Haneda, K., Okada, T., & Sadato, N. (2005). Linking semantic priming effect in functional MRI and event-related potentials. *Neuroimage*, *24*(3), 624-634.

Meinzer, M., Antonenko, D., Lindenberg, R., Hetzer, S., Ulm, L., Avirame, K., ... & Flöel, A. (2012). Electrical brain stimulation improves cognitive performance by modulating functional connectivity and task-specific activation. Journal of *Neuroscience, 32*(5), 1859-1866.

Pope, P. A., & Miall, R. C. (2012). Task-specific facilitation of cognition by cathodal transcranial direct current stimulation of the cerebellum. *Brain stimulation*, *5*(2), 84-94.

Poreisz, C., Boros, K., Antal, A., & Paulus, W. (2007). Safety aspects of transcranial direct current stimulation concerning healthy

subjects and patients. *Brain research bulletin, 72*(4-6), 208-214.

Poulisse, N. (1999). *Slips of the tongue: Speech errors in first and second language production*. Amsterdam, The Netherlands: John Benjamins.

Poulisse, N., & Bongaerts, T. (1994). First language use in second language production. *Applied Linguistics*, *15*, 36-57.

Rodriguez-Fornells, A., Kramer, U., Lorenzo-Seva, U., Festman, J., & Münte, T. F. (2012). Self-assessment of individual differences in language switching. *Frontiers in Psychology, 2*, 388.

Seo, R., Stocco, A., & Prat, C. S. (2018). The bilingual language network: Differential involvement of anterior cingulate, basal ganglia and prefrontal cortex in preparation, monitoring, and execution. *Neuroimage*, *174*, 44-56.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of experimental psychology: Human learning and memory*, *6*(2), 174.

Stagg, C. J., & Nitsche, M. A. (2011). Physiological basis of transcranial direct current stimulation. *The Neuroscientist, 17*(1), 37-53.

Verhoef, K., Roelofs, A., & Chwilla, D. (2009). Role of inhibition in language switching: Evidence from event-related brain potentials in overt picture naming. *Cognition*, *110*, 84–99.

Verhoef, K. M. W., Roelofs, A., & Chwilla, D. J. (2010). Electrophysiological Evidence for Endogenous Control of Attention in Switching between Languages in Overt Picture Naming. *Journal of Cognitive Neuroscience, 22*(8), 1832-1843.

Weiss, M., & Lavidor, M. (2012). When less is more: evidence for a facilitative cathodal tDCS effect in attentional abilities. *Journal of cognitive neuroscience*, *24*(9), 1826-1833.

Wise, R., Chollet, F., Hadar, U. R. I., Friston, K., Hoffner, E., & Frackowiak, R. (1991). Distribution of cortical neural networks involved in word comprehension and word retrieval. *Brain, 114*(4), 1803-1817.

Zhang, Q. F., & Yang, Y. F. (2003). The determiners of picture naming latency. *Acta Psychologica Sinica, 35*(4), 447-454.