

Effects of transcranial direct current stimulation over the Broca's area on tongue twister production

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Abstract

Purpose: The present study aimed to explore the short-term effect of anodal transcranial direct current stimulation (tDCS) on tongue twister production.

Method: Thirty healthy native Cantonese adult speakers were randomly assigned to the anodal tDCS group or the sham tDCS group. Anodal tDCS of 2 mA was applied over the Broca's area of the brain. The stimulation lasted for 20 min for the anodal tDCS group and 30 s for the sham tDCS group. The participants were instructed to produce a list of tongue twisters before, immediately after and 4 h after tDCS.

Result: Speech rate and response accuracy measured immediately after stimulation were significantly faster and higher, respectively, than before stimulation. Although there was no change in speech rate measured at 4 h after stimulation, response accuracy at that time point was significantly lower than that measured immediately after stimulation. However, there were no significant differences between the anodal tDCS and sham tDCS groups in either speech rate or response accuracy.

Conclusion: The findings revealed that a single session of anodal tDCS over the Broca's area did not significantly improve speech production during tongue twister production.

Keywords: *speech; transcranial direct current stimulation; Broca; tongue twister*

Introduction

In recent years, transcranial direct current stimulation (tDCS) has been widely used as a non-invasive brain stimulation technique to modulate cognitive functions and motor behaviours in both healthy and brain-damaged individuals (Adeyemo, Simis, Macea, & Fregni, 2012; Bastani & Jaberzadeh, 2012; Flöel, 2012; Kim et al., 2010; Sparing, Dafotakis, Meister, Thirugnanasambandam, & Fink, 2008). Research has shown that tDCS can be used to modulate motor cortex excitability in a non-invasive, reversible, selective and focal way (Nitsche & Paulus, 2000).

During tDCS, a low amplitude direct current (typically between 0.5 and 2.0 mA) is transmitted through the scalp and skull to a specific cortical region *via* two electrodes placed on the scalp. The exact stimulation effect depends on the polarity of the current. Generally, an anodal tDCS promotes cortical excitability whereas cathodal tDCS

decreases it (Nitsche & Paulus, 2000). The mechanism of acute effect during stimulation has been discussed at length in the literature. Essentially, tDCS modulates brain function by inducing the neuron's resting membrane potential to depolarise or hyperpolarise. When an anodal tDCS is delivered, the electric current causes a depolarisation of the resting membrane potential, which increases neuronal excitability and allows more spontaneous neuronal cell firing. Cortical excitability is therefore promoted by anodal tDCS. On the contrary, delivery of a cathodal tDCS induces hyperpolarisation of the resting membrane potential, thus reducing spontaneous cell firing and decreasing cortical excitability (Nitsche & Paulus, 2000). Research in healthy individuals has shown that anodal tDCS enhances motor learning (Nitsche et al., 2003), verbal fluency (Cattaneo, Pisoni, & Papagno, 2011), visuomotor performance (Antal et al., 2004) and working memory (Fregni et al., 2005). On the other

hand, it has been proposed that cathodal tDCS may reduce performance in working memory task (Berryhill, Wencil, Branch Coslett, & Olson, 2010) or may not have a significant effect on a learning task (Nitsche et al., 2003).

In the domain of speech production, recent reports have highlighted the beneficial effects of anodal tDCS over Broca's area on speech performance. Cattaneo et al. (2011) investigated the effects of anodal tDCS over Broca's area on verbal fluency in 10 healthy individuals, and found that the participants produced more words in phonemic and semantic fluency tasks following real stimulation as compared to sham stimulation. Similar anodal tDCS effects on verbal fluency were reported by Iyer et al. (2005), in which verbal fluency was found to improve significantly in the anodal tDCS group and decreased mildly in the cathodal tDCS stimulation group. Aside from verbal fluency, Holland et al. (2011) have shown that anodal tDCS over the Broca's area has significant facilitative effect on picture naming in healthy individuals. Concurrent magnetic resonance imaging (MRI) has also shown that the neural facilitation effect was regionally specific to the Broca's area and was positively correlated with improvement in naming responses (Holland et al., 2011). Fiori, Cipollari, Caltagirone, and Marangolo (2014) examined the effects of tDCS over the left frontal region on speech repetition and reported more accurate and faster tongue twister production during anodal stimulation as compared to pre- and post-stimulation. On the other hand, cathodal tDCS significantly reduced tongue twisters repetition accuracy and increased reaction time (Fiori et al., 2014). These findings indicated that enhancement of frontal lobe activity, including Broca's area, might have a positive effect on articulation and suggested that left frontal region may play an important role in the process of speech production.

Although our present knowledge of the relationship between Broca's area and speech production is still limited, it is undeniable that Broca's area plays a role in the neural circuitry of speech production (Kent, Kent, Weismer, & Duffy, 2000). Some studies have tried to explore the connection between Broca's area and speech production by examining speech production in individuals with a brain injury (e.g. stroke), reporting that Broca's area may play a crucial role in speech articulation (Hillis et al., 2004; Marangolo, Fiori, Calpagnano, et al., 2013; Marangolo, Fiori, Cipollari, et al., 2013; Marangolo et al., 2011). Hillis et al. (2004) examined the relationship between dysfunctional brain regions and speech articulation using MRI in 80 post-stroke patients. Results showed a strong association between apraxia of speech and dysfunction of Broca's area. As such, they concluded that the inferior frontal gyrus region, where Broca's area

was located, was strongly and critically involved in speech articulation. In a tDCS study, Marangolo et al. (2011) applied anodal tDCS for 20 min over the left inferior frontal gyrus of three chronic aphasic patients while performing a speech repetition task. After five consecutive days of tDCS with concurrent language therapy, greater response accuracy was reported following the anodic stimulation. Similar positive effects on articulation were reported in another study with eight chronic patients who underwent bihemispheric stimulation over the left and right frontal regions together with concurrent speech therapy (Marangolo, Fiori, Cipollari, et al., 2013).

Fiori et al. (2014) showed that when anodal tDCS was delivered over the Broca's area during tongue twister repetition, increased response accuracy and faster vocal reaction time were documented when compared to pre-stimulation and 1-h post-stimulation. In an effort to explore the lasting effect of a single session of tDCS, the present study aimed to further examine the short-term effect of tDCS on a tongue twister production task. The present study investigated the immediate after-effect as well as short-term effect (i.e. 4 h post stimulation) of anodal tDCS on tongue twister production. Research has shown that the duration of electrophysiological effects of tDCS outlasts the duration of stimulation. For example, the after-effect of 1 mA tDCS lasting for 9–13 min may last up to 90 min (Nitsche & Paulus, 2001; Nitsche et al., 2003; Zheng, Alsop, & Schlaug, 2011). Based on the reported literature, it may be assumed that there will be no effect of anodal tDCS on tongue twister production four hours after stimulation. Therefore, it is hypothesised that anodal tDCS over the Broca's area (F5) will enhance speech rate and response accuracy during tongue twister production and the effect will be maintained immediately after the stimulation but not at 4 h after stimulation.

Method

Participants

Thirty adults (10 males and 20 females) aged from 19 to 53 years ($M = 27.36$ years, $SD = 11.26$ years) with normal hearing were recruited for the study. All participants were native speakers of Cantonese with no history of speech or language pathology, brain surgery, seizure or stroke. In addition, they were free of any electrical or metallic implanted device in their body. The participants were randomly assigned to the anodal tDCS group ($n = 15$) or the sham group ($n = 15$). The research was approved by Human Research Ethics Committee of the University of Hong Kong. All the participants gave their informed consent to participate in the study.

Procedure

Delivery of tDCS

tDCS was delivered using a constant direct current stimulator (Chattanooga Ionto, Salty Lake, UT) via a pair of saline-soaked sponge electrodes (50 mm × 70 mm EasyPads, Soterix Medical Inc., New York, NY). The anodal electrode was centred over F5 based on the extended International 10–20 system for EEG electrode placement, which corresponded best to the Broca's area (Marangolo, Fiori, Calpagnano, et al., 2013; Naeser et al., 2010). The cathodal electrode was positioned over the contralateral frontopolar cortex (Fp2 of the extended International 10–20 system for EEG electrode placement). Previous studies have reported that the use of 35 cm² wet sponge with a direct current of 2 mA applied over the human cortex for up to 20 min is considered safe (Iyer et al., 2005; Nitsche & Paulus, 2001) and has resulted in only isolated reports on injury limited to skin irritation under the sponges (Bikson, Datta, & Elwassif, 2009). Therefore, anodal tDCS was applied at 2 mA for 20 min in this study. For the sham tDCS group, similar to anodal tDCS, electrodes were placed on the scalp for 20 min but the stimulation only lasted for 30 s in order to trigger similar sensation on the scalp as the anodal tDCS group.

Experimental task

Twenty-one Cantonese tongue twisters of different lengths and difficulties were included as stimuli (see Supplementary Appendixes 1 and 2). Tongue twisters were used instead of normal sentences because they are formed by groups of phonetically similar words purposely made difficult to articulate. These Cantonese tongue twisters were constructed by a close sequence of similar consonant sounds. Some of them also had a close sequence of similar vowel sounds and lexical tones. The production of tongue twisters involves more complex articulatory movements than normal speech, and was reported to be sensitive to potential effects of tDCS stimulation over the Broca's area (Fiori et al., 2014). The length of tongue twisters selected varied from five words/characters to 67 words/characters per tongue twister. Taking into consideration the length of the tongue twisters and the fact that retaining auditory information may increase working memory load (Chen & Cowen, 2009), the stimuli were presented visually.

The tongue twisters were presented in a random order using the E-Prime[®] 2.0 Professional (Psychology Software Tools, Inc., Sharpsburg, PA). Prior to the presentation of each tongue twister, a fixation cross was presented on the computer screen for 2 s to prepare the participants of the upcoming stimulus. When a tongue twister was presented, the participants were asked to read aloud the tongue twister as fast and accurately as possible. The tongue

twisters remained on the screen for the duration of the tongue twister production.

After the production of first block of tongue twisters, tDCS was set up on participants' head. The 2 mA anodal tDCS lasted for 20 min while the sham tDCS lasted for 30 s. The participants were advised to sit back and relax during stimulation. Upon completion of tDCS stimulation, the participants were asked to read aloud the second block of tongue twisters. The tongue twisters used in each block were identical but randomised in a different order. Again, the participants were instructed to read aloud the tongue twisters as fast and accurately as possible. The participants also repeated the tongue twister production task 4 h after the offset of tDCS and they were reminded not to practice the tongue twisters between sessions. Speech produced by participants was recorded using *praat* through a high-quality microphone (SM59A, Shure, Evanston, IL) and a pre-amplification system (MOTU MicroBook II, Cambridge, MA). A sampling frequency of 44 kHz and quantisation rate of 16 bits/sample was used.

Data analysis

Speech rate and accuracy during tongue twister production before tDCS (pre-tDCS), immediately after tDCS (post-1) and 4 h after tDCS (post-2) were obtained. Speech rate (words per second, WPS) was calculated by dividing the total number of words produced by duration (in seconds) from onset to the offset of the participant's response. Speech rate was calculated using WPS because Cantonese words (or characters) are monosyllabic (Bauer & Benedict, 1997). Words that were produced incorrectly or produced as self-corrections were included. Speech accuracy (%) was calculated by dividing the number of words produced correctly by the total number of words in a tongue twister. Self-corrections during tongue twister production were not judged as syllables produced correctly.

Statistical analysis

A series of repeated-measures analyses of variance (ANOVA) were performed for speech rate and response accuracy with *time* as a within-subject factor (pre-tDCS, post-1 and post-2) and *group* as a between-subjects factor (anodal vs. sham stimulation). All 21 tongue twisters were included for analyses. A *p* value of 0.05 was adopted as the level of significance.

Result

The mean speech rate and response accuracy measured before stimulation (pre-tDCS), immediately after stimulation (post-1) and 4 h after stimulation (post-2) are displayed in Figure 1. The mean and standard deviation of speech rate and response

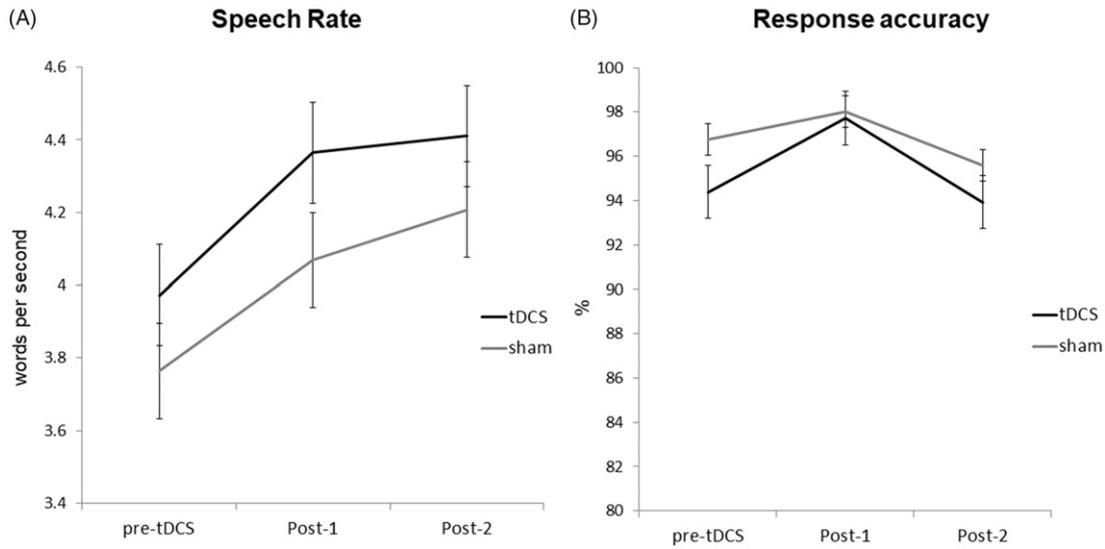


Figure 1. Mean speech rate and response accuracy during pre-tDCS, post-1 and post-2 measurements.

Table I. Mean (and standard deviation) speech rate (words per second) measured for the anodal and sham tDCS groups before stimulation (pre), immediately after stimulation (post-1) and at 4 h after stimulation (post-2).

Tongue twisters	Anodal tDCS (n = 15)			Sham tDCS (n = 15)		
	Mean (SD)			Mean (SD)		
	Pre	Post-1	Post-2	Pre	Post-1	Post-2
1	3.98 (0.71)	4.47 (0.78)	4.64 (0.83)	3.68 (0.79)	4.24 (0.85)	4.17 (0.86)
2	2.82 (0.83)	3.26 (1.02)	3.04 (0.68)	2.58 (0.69)	2.69 (0.75)	2.75 (0.80)
3	5.51 (1.37)	5.52 (0.99)	5.76 (1.13)	4.72 (0.83)	5.26 (1.06)	5.40 (0.85)
4	4.03 (0.60)	4.50 (0.72)	4.49 (0.82)	3.94 (0.76)	4.33 (0.78)	4.68 (1.50)
5	2.82 (0.66)	3.22 (0.63)	3.16 (0.79)	2.83 (0.57)	3.03 (0.59)	3.02 (0.69)
6	3.66 (0.84)	3.88 (0.97)	4.05 (1.08)	3.13 (0.50)	3.66 (0.62)	3.85 (0.42)
7	4.23 (0.82)	4.70 (0.70)	4.66 (0.79)	3.96 (0.68)	4.01 (0.80)	4.53 (0.71)
8	4.59 (0.73)	4.90 (0.89)	5.04 (1.03)	4.50 (0.78)	4.72 (0.53)	4.87 (0.54)
9	4.90 (1.01)	5.40 (0.81)	5.66 (0.90)	4.84 (0.96)	5.18 (1.09)	5.49 (1.03)
10	4.32 (0.93)	4.84 (1.04)	4.84 (0.95)	4.12 (0.74)	4.47 (0.84)	4.62 (0.87)
11	4.44 (1.04)	4.36 (0.89)	4.62 (1.03)	3.62 (0.72)	4.00 (0.90)	4.24 (0.95)
12	3.30 (0.90)	4.02 (0.91)	3.86 (0.85)	3.13 (0.73)	3.56 (0.64)	3.51 (0.67)
13	5.40 (0.92)	6.02 (0.96)	6.18 (1.17)	5.22 (1.25)	5.75 (0.97)	6.25 (0.96)
14	4.24 (0.61)	4.70 (0.81)	4.85 (0.86)	4.10 (0.72)	4.24 (0.74)	4.66 (0.79)
15	3.45 (0.64)	3.93 (0.86)	3.98 (0.78)	3.28 (0.36)	3.60 (0.45)	3.75 (0.43)
16	4.12 (1.15)	4.56 (1.23)	4.56 (1.13)	4.35 (1.02)	4.25 (0.86)	4.04 (1.02)
17	4.24 (1.04)	4.62 (1.10)	4.58 (0.95)	4.22 (0.98)	4.52 (1.00)	4.78 (1.53)
18	2.23 (0.73)	2.67 (0.64)	2.40 (0.42)	2.20 (0.43)	2.36 (0.41)	2.53 (0.47)
19	4.02 (1.16)	4.52 (1.12)	4.40 (0.83)	4.20 (1.24)	4.27 (1.10)	3.95 (1.10)
20	3.94 (0.83)	4.10 (0.77)	4.17 (0.69)	3.77 (0.58)	4.10 (1.03)	4.03 (0.59)
21	3.19 (0.92)	3.45 (0.70)	3.71 (0.58)	2.69 (0.48)	3.23 (0.56)	3.25 (0.57)

accuracy measured for each tongue twister during the three time-points are displayed in Tables I and II.

Speech rate

Results showed a significant main effect for time [$F(2, 24) = 38.911, p < 0.001, \eta^2 = 0.764$] and tongue twisters [$F(20, 6) = 20.349, p = 0.001, \eta^2 = 0.985$]. *Post hoc* pairwise comparisons with Bonferroni adjustment revealed that speech rates measured immediately after stimulation and 4 h after stimulation were significantly faster than before stimulation; with no difference in speech rate measured immediately after stimulation and 4 h after stimulation found. However, there were no

significant differences in speech rate measured between the anodal and sham tDCS groups ($p = 0.29$).

Response accuracy

Results showed a significant main effect for time [$F(2, 24) = 26.230, p < 0.001, \eta^2 = 0.686$] and tongue twisters [$F(20, 6) = 8.214, p < 0.01, \eta^2 = 0.965$]. *Post hoc* pairwise comparisons with Bonferroni adjustment revealed significantly higher response accuracy immediately after stimulation and response accuracy measured at 4 h after stimulation were significantly lower than immediately after stimulation. There were no significant differences

Table II. Mean (and standard deviation) response accuracy (%) measured for anodal and sham tDCS groups before stimulation (pre), immediately after stimulation (post-1) and at 4 h after stimulation (post-2).

Tongue twister	Anodal tDCS (<i>n</i> = 15)			Sham tDCS (<i>n</i> = 15)		
	Mean (SD)			Mean (SD)		
	Pre	Post-1	Post-2	Pre	Post-1	Post-2
1	98.38 (2.29)	97.37 (2.15)	98.38 (2.53)	97.18 (3.00)	98.31 (2.22)	97.18 (2.82)
2	83.03 (7.02)	77.34 (9.72)	81.01 (7.62)	87.27 (10.85)	93.79 (12.26)	89.44 (11.15)
3	98.08 (2.77)	99.18 (1.57)	99.18 (1.57)	100.00 (0.00)	98.87 (2.53)	99.49 (1.30)
4	97.77 (1.81)	98.38 (2.02)	98.38 (3.14)	98.50 (1.70)	98.87 (1.70)	98.50 (2.87)
5	88.46 (6.86)	93.68 (6.21)	92.86 (5.26)	97.19 (3.19)	96.43 (4.65)	98.21 (2.71)
6	93.27 (8.25)	97.12 (5.48)	94.23 (8.25)	97.32 (5.32)	96.43 (7.64)	93.75 (11.76)
7	97.90 (2.53)	99.30 (1.43)	98.60 (1.98)	98.38 (2.59)	97.56 (3.73)	99.51 (0.97)
8	99.11 (2.30)	99.70 (1.07)	100.00 (0.00)	99.45 (1.40)	99.73 (1.03)	99.73 (1.03)
9	94.33 (5.87)	98.38 (2.53)	98.38 (3.32)	98.50 (3.22)	97.74 (5.73)	100.00 (0.00)
10	98.66 (2.74)	99.67 (1.21)	98.66 (2.74)	99.07 (2.52)	97.83 (2.26)	99.07 (1.85)
11	95.19 (9.60)	98.08 (4.69)	93.27 (8.25)	95.54 (9.31)	94.64 (11.72)	95.54 (10.52)
12	95.55 (3.29)	97.37 (3.56)	96.76 (3.75)	96.99 (2.89)	97.56 (2.41)	97.93 (2.87)
13	99.47 (1.29)	98.67 (2.24)	99.20 (2.07)	98.77 (1.71)	99.01 (1.62)	99.01 (2.11)
14	96.45 (1.67)	97.63 (2.21)	97.63 (1.64)	97.07 (2.99)	97.25 (2.35)	97.99 (2.29)
15	97.24 (2.78)	95.06 (6.31)	96.33 (3.69)	96.91 (2.52)	97.23 (3.14)	97.23 (3.20)
16	93.59 (7.72)	88.78 (14.96)	91.67 (11.79)	91.67 (10.84)	88.69 (10.65)	91.07 (8.93)
17	97.16 (4.20)	97.83 (2.17)	98.33 (2.83)	98.60 (1.62)	98.60 (1.83)	98.60 (1.83)
18	86.15 (20.63)	89.23 (15.53)	84.62 (20.25)	94.29 (9.38)	95.71 (16.04)	95.71 (8.52)
19	94.67 (5.78)	94.67 (7.94)	97.63 (3.70)	95.60 (3.95)	96.70 (4.97)	94.51 (8.76)
20	96.48 (2.89)	94.29 (4.04)	96.70 (2.29)	96.33 (3.79)	96.33 (4.81)	97.14 (4.88)
21	91.51 (7.44)	94.23 (4.35)	96.31 (5.46)	93.45 (4.89)	96.13 (3.04)	96.58 (3.80)

in response accuracy measured before stimulation and 4 h after stimulation and between the anodal and sham tDCS groups ($p = 0.11$).

Discussion

It was hypothesised that speech rate and response accuracy would improve immediately after anodal tDCS and return to pre-tDCS level 4 h after the stimulation. However, the results showed that speech rate measured immediately after both anodal and sham tDCS were significantly faster than before stimulation and the performance of the anodal tDCS group was not significantly better than the sham tDCS group. At 4 h after stimulation, speech rate was maintained and did not return to pre-tDCS level. Fiori et al. (2014) conducted a similar study to examine the modulation effect of tDCS during tongue twister repetition. Fiori and colleague (2014) provided auditory stimuli to their participants and recorded their vocal reaction time and response accuracy during tongue twister repetition 1 h before stimulation, during stimulation and 1 h after stimulation was completed. Fiori et al. (2014) reported significantly faster vocal reaction time and higher response accuracy during anodal tDCS stimulation when compared to pre- and post-stimulation. Yet, the sham group did not show significant changes in both vocal reaction time and response accuracy in the three time periods.

The present findings are somewhat different from Fiori et al. (2014). It may be due to the differences in methodologies employed in the studies, including the methods of stimulus presentation (visually vs. auditory), the behavioural tasks (reading aloud vs. repetition), timing of data collection in relation to stimulation (pre-stimulation, immediately and 4 h

after stimulation vs. 1 h before stimulation, during stimulation and 1 h after stimulation), as well as the type of outcome measures used (speech rate vs. vocal reaction time). The present study opted to present the tongue twisters as visual stimuli for a reading aloud task after considering the possibility of increased working memory load in retaining verbal stimuli for a repetition task as well as considering the length of stimuli up to 67 words/characters per tongue twister. The time at which data was collected also varied between the studies. Fiori et al. (2014) aimed to explore the modulation effects of anodal, cathodal and sham tDCS on speech repetition. Based on the reported modulation effects of tDCS, the present study further investigated the immediate after effect (immediately after stimulation) as well as short-term effects (4 h after stimulation) of tDCS on speech performance. In Fiori et al. (2014), vocal reaction time was defined as the duration between offset of auditory stimulus to the offset of the participants' response, which also took into account the duration of the participants' response. A reduction in vocal response time in their study may have been contributed by the increased speech rate during anodal tDCS. The present findings show that speech rate measured immediately after stimulation was significantly faster than before stimulation, and these phenomena were observed in both the anodal and sham tDCS groups. It was noted that Fiori et al. (2014) reported no significant changes in vocal reaction time measured in the sham group in the three time periods.

Practice effects may have played an important role in masking the effects of anodal tDCS in the study. The present study used the same list of tongue twisters for all three measurements. Although the tongue twisters were randomised and resulted in

different orders for each measurement, practice effect could not be ruled out. The contribution of practice effect was more apparent when examining the mean speech rate for the sham tDCS group where there was a more obvious trend of increasing speech rate from pre-tDCS to post-1 and post-2 measurements despite there should be no stimulation effects. Additionally the participants involved in the present study (mean age = 27 years) are relatively younger than those involved in Fiori et al. (2014) with a mean age of 57. According to Pascual-Leone et al. (2011), brain plasticity was important in acquisition of new skills and the efficiency of neuronal plasticity declined throughout the age-span. To put it another way, efficiency of learning may decline with age. As the present study involved a younger group of participants, thus the practice effects may be larger resulting in a better performance in post-2 measurement than expected.

The findings also revealed significantly higher response accuracy immediately after tDCS stimulation compared to before stimulation and 4 h after stimulation. This finding was consistent with Fiori et al. (2014) which reported an increased response accuracy after anodal tDCS stimulation. Although there were no significant differences between the anodal and sham tDCS groups, the anodal tDCS group was observed to have a higher gain in response accuracy immediately after stimulation.

Limitations and future direction

The findings from the present study should be interpreted cautiously. As mentioned previously, practice effect may be present in the study that could mask the effects of tDCS. Future studies may use three different lists of tongue twisters with similar difficulties for pre-tDCS, post-1 and post-2 measurements. In addition, the present study only involved healthy individuals as participants and the possibility of translating the results into populations with speech pathology (e.g. dysarthria) is still unknown. Further studies are encouraged to examine if multiple sessions of anodal tDCS may achieve persistent beneficial effects to enhance speech production. A few studies have evaluated the potential of multiple sessions of anodal tDCS in facilitating language and speech recovery in individuals with stroke. It was reported that, when paired with conventional therapy, positive effects up to 2 months after stimulation were documented (Fridriksson, Richardson, Baker, & Rorden, 2011; Marangolo, Fiori, Calpagnano, et al., 2013; Marangolo, Fiori, Cipollari, et al., 2013; Marangolo et al., 2011). The sustainable effects of tDCS indicating the modulatory mechanism of tDCS may not be solely attributed to changes in neuronal electrical potential of neuronal membrane. It was proposed the sustainable effect of tDCS may be explained by neuroplasticity, which refers to the

ability of the neural pathways and synapses in brain to change throughout life based on changes in behaviour, environment, neural processes, thinking and emotions (Pascual-Leone et al., 2011). The effect of tDCS is hypothesised to be similar to those observed in long-term potentiation (LTP) and long-term depression (LTD). LTP refers to the strengthening between two neurons through an alteration of synaptic transmission ability whereas LTD refers to the weakening between two neurons. Fritsch et al. (2010) showed that anodal tDCS of the motor cortex induced a lasting increase in postsynaptic excitatory potentials in animals, which was similar to that in LTP. Nonetheless, our present knowledge about how tDCS promotes neuronal plasticity is limited. The actual mechanism of tDCS still remains to be fully elucidated (Brunoni et al., 2012).

Conclusion

The present study documented that a single session of anodal tDCS over the Broca's area failed to yield improved speech rate and response accuracy during tongue twisters production in healthy individuals.

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Declaration of interest

The authors report no conflicts of interest.

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Supplementary material

Supplemental data for this article can be accessed at <http://dx.doi.org/10.1080/17549507.2017.1417480>

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