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Lie-Specific Involvement of Dorsolateral Prefrontal Cortex in Deception

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Lies are intentional distortions of event knowledge. No experimental data are available on manipulating lying processes. To address this issue, we stimulated the dorsolateral prefrontal cortex (DLPFC) using transcranial direct current stimulation (tDCS). Fifteen healthy volunteers were tested before and after tDCS (anodal, cathodal, and sham). Two types of truthful (truthful selected: TS; truthful unselected: TU) and deceptive (lie selected: LS; lie unselected: LU) responses were evaluated using a computer-controlled task. Reaction times (RTs) and accuracy were collected and used as dependent variables. In the baseline task, the RT was significantly longer for lie responses than for true responses ([mean ± standard error] 1153.4 ± 42.0 ms vs. 1039.6 ± 36.6 ms; $F_{1,14} = 27.25$, $P = 0.00013$). At baseline, RT for selected pictures was significantly shorter than RT for unselected pictures (1051.26 ± 39.0 ms vs. 1141.76 ± 41.1 ms; $F_{1,14} = 34.85$, $P = 0.00004$). Whereas after cathodal and sham stimulation, lie responses remained unchanged (cathodal 5.26 ± 2.7%; sham 5.66 ± 3.6%), after anodal tDCS, RTs significantly increased but did so only for LS responses (16.86 ± 5.0%; $P = 0.002$). These findings show that manipulation of brain function with DLPFC tDCS specifically influences experimental deception and that distinctive neural mechanisms underlie different types of lies.

Keywords: deception, frontal cortex, human, lies, tDCS

Introduction

Lies are intentional distortions of event knowledge, generally aimed at instilling a false belief (Ekman and O'Sullivan 1991). The scientific interest about lies has gained momentum owing to the increased needs of the defence, investigative, and forensic settings. Research on deception has nevertheless focused primarily on lie detection techniques and on the neural correlates of lies (Spence et al. 2004). Rather than being a unique cognitive process, lies involve several different elementary cognitive processes, among them working memory, set shifting, and response inhibition (Johnson et al. 2004; Langleben et al. 2005). Lies also differ in type (Ganis et al. 2003). For instance, deception for past events is divided into 2 types, deception for experienced events (pretending not to know) and for new events (pretending to know) (Abe et al. 2006). In a hypothetical continuum, lies vary from simple false yes/no responses to complex narrative production such as lies implied in a false alibi. Hence, distinctly different brain processes probably underlie the various types of lying. No experimental data are available on manipulating or interfering with the deception cognitive process.

Transcranial direct current stimulation (tDCS) is a noninvasive technique that elicits functional changes in human brain, without needing a direct access to the neural tissue (Priori et al. 1998; Nitsche and Paulus 2000; Nitsche et al. 2003; Priori 2003; Fregni et al. 2005, 2006). Excitability changes after tDCS probably arise from more than one mechanism acting at synaptic and nonsynaptic levels (Ardolino et al. 2005). The technique has been used to modulate excitability in the human motor and visual cortices (Nitsche and Paulus 2000; Rosenkranz et al. 2000; Antal et al. 2001, 2004, 2006; Baudewig et al. 2001; Cogiamanian et al. 2007) to influence reaction times (RTs) (Marshall et al. 2005), motor learning, visual–motor coordination tasks, and also cognitive functions such as probabilistic classification learning (Kincses et al. 2004). Functional neuroimaging studies showed that tDCS elicits long-lasting functional changes in the brain (Lang et al. 2005). Hence, tDCS can be used to modulate the activity of brain regions implicated in the planning or execution of specific behavioral and cognitive tasks.

We aimed to assess whether changes in the excitability of the human prefrontal cortex influence the cognitive processes involved in deception. To do so, we delivered tDCS over the dorsolateral prefrontal cortex (DLPFC—Brodmann's areas [BAs] 9 and 46), a brain site previously implicated in lie production (Ganis et al. 2003; Langleben et al. 2005; Nunez et al. 2005; Phan et al. 2005; Abe et al. 2006). Although deception in real life involves complex cognitive mechanisms, the protocol we used for this experimental study on deception assesses the basic processes for lying. Before and after tDCS, truthful and deceptive responses were evaluated using a computer-controlled procedure testing 2 types of lies: denying a fact that really happened and producing a false response about an event that did not happen.

Materials and Methods

Subjects

The study was approved by the ethics committee for the Fondazione IRRCS Ospedale Maggiore Policlinico, Mangiagalli e Regina Elena, Milan, Italy and was conducted according to the ethical standards laid down in the Declaration of Helsinki. After written informed consent, 15 healthy volunteers were tested (mean age = 31.5 years; average education = 19.6 years).

Transcranial Direct Current Stimulation

tDCS was bilaterally delivered by 2 electrical constant direct current stimulators each connected to a pair of sponge electrodes, one placed on the scalp over one DLPFC side and the other over the right deltoid muscle. Scalp electrodes were positioned over F3 and F4 according to the 10–20 EEG international system. To avoid confounding biases arising from 2 electrodes with opposite polarities over the scalp, we used a noncephalic reference electrode for tDCS (Cogiamanian et al. 2007). The electrodes used for tDCS were thick (0.3 cm), rectangular saline-soaked synthetic sponges (scalp electrode 32 cm^2; deltoid electrode 64 cm^2). Anodal or cathodal tDCS polarity refers to the electrodes over the scalp (F3 and F4). The stimulus was an anodal or cathodal DC at 1.5 mA

intensity delivered for 10 min over DLPFC bilaterally (0.03 C/cm^2). We ramped the current up over the first 5 s of stimulation and down over the last 5 s and kept tDCS below perceptual threshold throughout the experimental session. For sham stimulation, electrodes placement was identical to real stimulation but the stimulator was turned off after 10 s.

Subjects were tested before and after tDCS (anodal, cathodal, and sham) (Fig. 1). Each participant was administered the test sequence (prestimulation and 90 s poststimulation) 3 times, once each for anodal, cathodal, and sham tDCS. The order of stimulation across the 3 sessions was counterbalanced across the participants and one week elapsed between subsequent sessions.

Experimental Design

Truthful and deceptive responses were evaluated using a computer-controlled procedure, a simplified version of the task used by Langleben and coworkers (Langleben et al. 2002, 2005). In brief, subjects were first required to select 5 pictures (i.e., selected pictures) from a set of 10. To avoid spurious response variations due to stimulus memorizability, the 10 pictures were selected to have a similar familiarity (average familiarity = 5.54; standard deviation [SD] = 1.5), frequency (average frequency = 2.33; SD = 0.3), and age-of-acquisition (average AoA = 2.89; SD = 0.61). The pictures and the corresponding parameters were taken from Dell'Acqua's et al. database collected on Italian subjects (2000). They were then requested to answer truthfully or to lie to the question "do you have this picture?" referring to a picture randomly presented on the computer screen: 50% of the times the picture was one of those selected and 50% of the times it was one of those not selected, with a total of 80 trials. Twenty stimuli required a truthful response to selected pictures (TS: responding truthfully to a selected picture) and 20 to unselected pictures (TU: responding truthfully to an unselected picture); 20 stimuli required to lie to selected pictures (LS: lying to a selected picture) and 20 to unselected pictures (LU: lying to an unselected picture). Hence, before each picture was presented, the participant was instructed by the computer to lie or to respond truthfully. We therefore tested 2 types of lies: denying a fact that really happened (i.e., LS) and producing a false response about an event that did not happen (i.e., LU). Three minutes of practice were allowed before the experimental session. In the baseline condition, all subjects performed the task without stimulation. After a 9-min baseline task, the participants were stimulated by tDCS for 10 min; 90 s after stimulation ended, subjects were retested with the same task (Fig. 1).

Statistical Analysis

RTs and accuracy were collected and used as dependent variables. A 3-way within-subjects analysis of variance (ANOVA) was run with tDCS (anodal, cathodal, and sham), picture type (selected and unselected), and instruction (truth and lie) as factors using Greenhouse–Geisser corrections. RTs and accuracy at poststimulation were expressed as the percent changes from their baseline value (=100%) and used as dependent variables. Tukey's honest significant difference post hoc test for multiple factor interactions was used ($P < 0.05$). Values in text are mean ± standard error of the mean.

Results

No difference was found in the baseline values of RTs and accuracy before tDCS across the 3 sessions (Table 1). In the baseline task, the RT was significantly longer for lie responses than for true responses (1153.4 ± 42.0 ms vs. 1039.6 ± 36.6 ms; $F_{1,14} = 27.25$, $P = 0.00013$). At baseline, RT for selected pictures was significantly shorter than RT for unselected pictures (1051.26 ± 39.0 ms vs. 1141.76 ± 41.1 ms; $F_{1,14} = 34.85$, $P = 0.00004$).

Anodal, cathodal, and sham tDCS neither had any influence on the accuracy of the responses ($F_{2,28} = 1.01$, $P = 0.24$) nor had elicited significant interactions with picture types and instruction ($F_{2,28} = 0.45$, $P = 0.64$). By contrast, anodal tDCS specifically modulated RTs for LS. Whereas the main factor tDCS and the main factor instruction produced no significant effect on data when all tasks were considered together (tDCS: $F_{2,28} = 1.01$, $P = 0.38$; instruction: $F_{1,14} = 3.23$, $P = 0.09$), the main factor "picture type" (unselected vs. selected pictures) produced a significant effect on RTs ($F_{1,14} = 10.20$, $P = 0.006$). ANOVA disclosed no significant 2-factors interaction (tDCS × picture type: $F_{2,28} = 2.01$, $P = 0.15$; tDCS × instruction: $F_{2,28} = 0.16$, $P = 0.85$; picture type × instruction: $F_{1,14} = 0.12$, $P = 0.74$). Conversely, it showed a significant interaction of tDCS × picture type × instruction ($F_{2,28} = 7.58$, $P = 0.002$). Post hoc test for 3-factors interaction revealed a significant difference between RT changes in LS responses after anodal tDCS and LS responses after sham tDCS (16.8 ± 5.0% vs. 5.6 ± 3.6%; $P = 0.023$) and after cathodal tDCS (5.2 ± 2.7%; $P = 0.017$). Post hoc analysis also disclosed that although anodal tDCS left the RTs for LU responses unchanged, the LS RTs (i.e., responding "no I did not select this picture" when in fact it was one of those selected) significantly increased by 16.9 ± 5.0% ($P = 0.028$, Fig. 1). Post hoc analysis identified no significant difference between LS RTs for cathodal tDCS and sham tDCS ($P = 0.99$).

Discussion

These new findings obtained by delivering tDCS to healthy volunteers in experiments designed to manipulate the human overt production of deceptive responses provide, to our knowledge for the first time, evidence that focal changes in the excitability of the human brain can experimentally influence lie production, altering the speed and efficiency of lying responses. The selective modulation of LS (lying to selected pictures) suggests that LS and LU (lying to unselected pictures) responses have distinct neural mechanisms. Our results show that the 2 types of lies tested respond differentially to anodal stimulation delivered over the DLPFC, a brain site previously implicated in lie production (Spence et al. 2001; Langleben et al. 2002; Ganis et al. 2003; Phan et al. 2005).

Methodological Considerations

The first important point to clarify in interpreting our findings is whether the lies we used in our experimental design resemble deception in real life. Despite the lack of the emotional and intentional components characterizing real lying, the task we administered provides a model for 2 subprocesses associated with deception, namely, inhibition of truthful responses (a process present even when the participant is instructed to lie) and producing a lie "pretending to know" or "pretending not to know." The 2 lie types can be modeled by administering previously selected pictures (lies selected, pretending not to know) and previously unselected pictures (lies unselected, pretending to know). The procedure we used here and described by Langleben et al. (2002) excludes those cognitive components that characterize more complex lies, for example, planning a complex narrative, holding in working memory interim production of the story, and intentionality. Conversely, the procedure shares, with more complex lies, the inhibition process (the truthful response must be blocked), set shifting, working memory (the selected pictures must be held in working memory), and conflict monitoring (conflict between the automatic truthful response and the lie response required by the instructions). We selected this task for 2 reasons: first, it is suitable for use in experiments involving brain stimulation (it is short, repeatable, and reliable also when delivered to the subjects at short intervals); second, its neural substrate is relatively well understood. A second point that should be

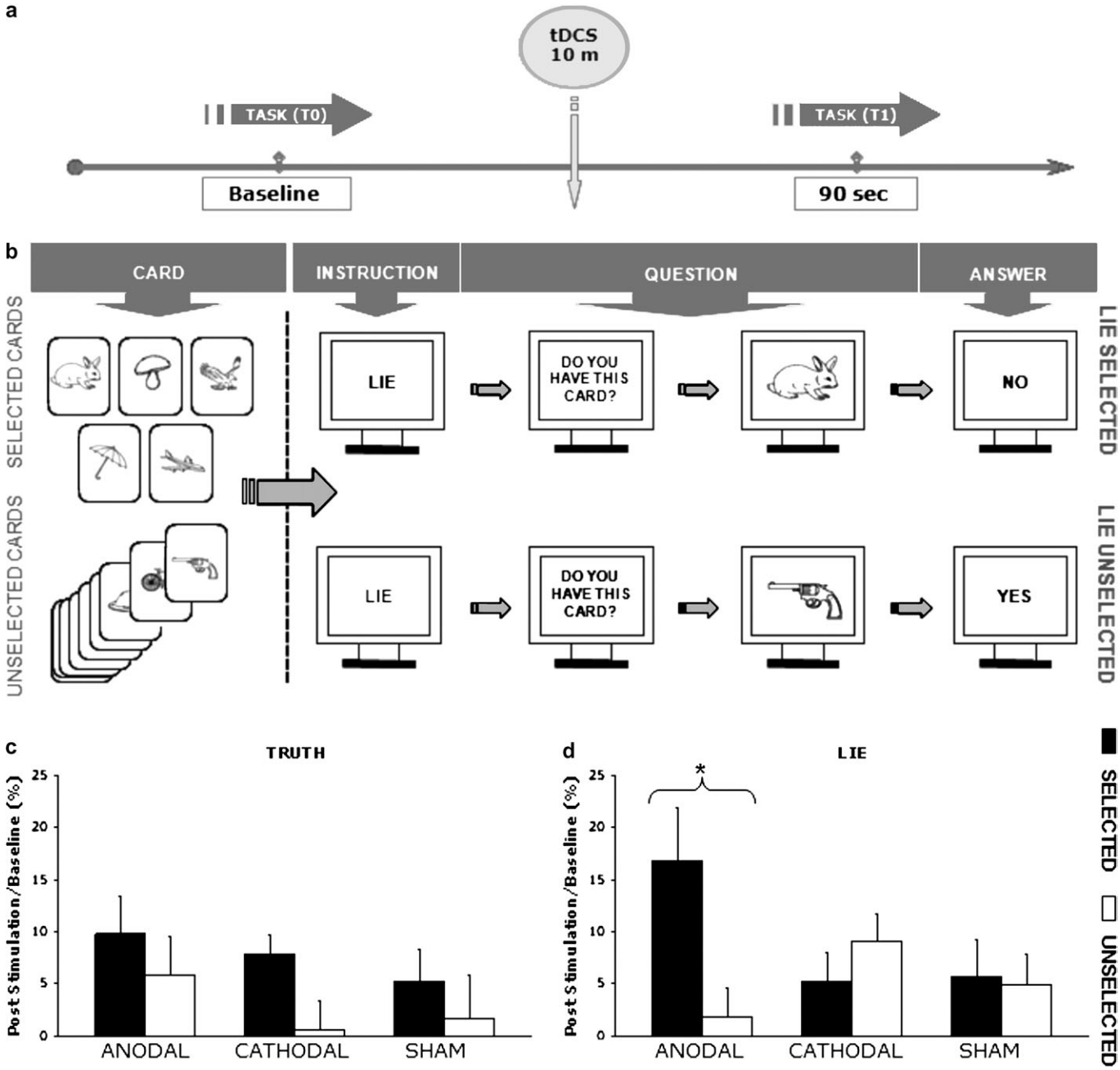

Figure 1. Effects of DLPFC tDCS on deception—(*a*) schematic diagram of the experimental design during a single session. The horizontal gray arrow is time; the vertical gray arrow represents tDCS over DLPFC. The task was administered once before stimulation (baseline, T0) and again 90 s after the end of tDCS stimulation (T1). (*b*) The task sequence for lie selected (LS) and unselected (LU) responses. The top gray horizontal line shows the different phases of the task. The middle panel represents the sequence for the lie selected (LS) responses and the lower panel the sequence for lie unselected (LU) responses. (*c*) RTs for truthful responses. The histograms represent the mean RT of the task performed 90 s after stimulation expressed as a percentage of the value obtained at the baseline for anodal, cathodal, and sham tDCS (the *x* axis). Solid histograms are the responses for selected pictures, and empty histograms are the responses for the unselected pictures. Note that RTs for truthful responses remained unchanged across different conditions. Error bars are standard error of the mean. (*d*) RTs for lie responses (the rest of the legend as in *c*). Note that, after anodal stimulation, the RTs for LU responses remain unchanged, whereas the LS RTs significantly increase (* = $P < 0.05$).

considered is that, even though our everyday life brings us into contact with lies of widely differing types, our experimental paradigm assesses externally cued lies. This distinction is important insofar as internally cued and externally cued lies might use different neural mechanisms. Finally, we chose the DLPFC because this brain area is specifically involved in the deception process and specifically activated during the guilty knowledge task, as demonstrated by Langleben et al. (2005). Our findings partly agree with neuroimaging studies showing that the DLPFC is involved in deceptive responses (Spence et al. 2001; Langleben et al. 2002; Ganis et al. 2003; Phan et al. 2005). Evidence suggesting DLPFC specificity for lie comes from fMRI studies reporting the selective activation of the inferior lateral prefrontal (BA 44–47) and medial superior frontal (BA 9) cortices in both salience-controlled and nonsalience-controlled lie contrasts (Langleben et al. 2005). The study by Abe et al.

Table 1
RT and accuracy

	Anodal		Cathodal		Sham	
	Before tDCS	After tDCS	Before tDCS	After tDCS	Before tDCS	After tDCS
RT						
TS	990.2 (83.0)	1102.1 (107.6)	965.1 (79.1)	1042.6 (88.5)	997.1 (101.0)	1027.8 (87.0)
TU	1109.3 (100.0)	1181.3 (116.6)	1090.5 (91.3)	1104.2 (104.3)	1084.9 (105.7)	1088.3 (99.1)
LS	1107.7 (106.6)	1293.9 (128.5)	1119.5 (95.3)	1188.5 (110.7)	1127.4 (110.4)	1181.6 (112.8)
LU	1203.7 (109.6)	1232.4 (119.7)	1171.7 (98.6)	1293.2 (119.7)	1189.9 (110.8)	1249.3 (117.6)
Accuracy						
TS	18.7 (0.43)	18.1 (0.64)	19.2 (0.28)	19.1 (0.21)	18.8 (0.40)	18.6 (0.34)
TU	19.0 (0.30)	18.2 (0.43)	19.2 (0.20)	18.9 (0.37)	18.9 (0.38)	18.3 (0.44)
LS	17.7 (0.53)	17.6 (0.49)	17.3 (0.42)	18.2 (0.31)	18.2 (0.30)	18.0 (0.51)
LU	18.2 (0.54)	17.7 (0.63)	18.2 (0.41)	18.4 (0.32)	18.2 (0.50)	17.8 (0.47)

Note: In the columns are listed the values before and after stimulation (anodal, cathodal, and sham) of truthful selected (TS) and truthful unselected (TU) responses, lies selected (LS) and lies unselected (LU) responses. Values are mean (standard error of the mean).

(2006) reported that DLPFC is activated, together with the ventrolateral prefrontal cortex, for both pretending to know and pretending not to know lies, whereas the anterior cingulated cortex (ACC) is selectively activated only during pretending not to know lies. Intriguingly, this study also pointed out that the regional cerebral blood flow in DLPFC positively correlates with that in the ACC only during pretending not to know lies, thereby suggesting a potential specificity of the coactivation of these regions in this particular lie type (Abe et al. 2006).

Implications for Deception Process Modeling

Our data suggest that tDCS-induced DLPFC involvement in lie production reflects a focal decrease in cortical excitability, presumably impairing prefrontal cortex function. Although a recent study using brain anodal tDCS found facilitatory effects (Marshall et al. 2005), monopolar anodal direct currents hyperpolarize peripheral axons ultimately leading to the "anodal block" (Priori et al. 2005). The first tDCS study in humans also reported the inhibitory effects of anodal tDCS in the motor cortex (Priori et al. 1998). The noncephalic placement of the reference electrode we used for tDCS generates an electric field whose geometry remarkably differs from that generated in previous studies (Marshall et al. 2005; Antal et al. 2006) that found an anodal tDCS–induced facilitation after placing both tDCS electrodes over the head. Yet, the geometry of the electric field can influence the biological effects of DC stimulation of a given polarity (Priori 2003). Although the localization of tDCS-induced effects remains controversial, the main effects are probably localized below the stimulating electrode. As shown by Positron Emission Tomography (PET) findings (Lang et al. 2005), although tDCS may also elicit distant effects, it elicits the major functional changes below the stimulating electrode, modulating the regional activity in the targeted cortex. Hence, although we cannot rule out the theoretical possibility of tDCS-induced changes in other brain areas, we believe that tDCS elicits the most important effect by modulating the DLPFC below the stimulating electrode.

Because DLPFC is linked with working memory (Smith and Jonides 1997; Fregni et al. 2005; Marshall et al. 2005; Boggio et al. 2006), our experimental paradigm using anodal tDCS over the DLPFC could in theory affect deception by influencing working memory more than deception itself. We consider an effect on working memory unlikely, however, because anodal tDCS specifically affected lies, whereas it left truthful responses unchanged.

A final important point is how our findings fit in with current knowledge on the neurophysiological basis of deceptive processes. The selective effect of anodal tDCS delivered over DLPFC on the LS response but not on the LU response is an intriguing finding and suggests that different types of lies imply distinctive and specific neural mechanisms. In our experiments, anodal tDCS had no effect on motor responses because RTs would have increased for all types of stimuli, whereas they did not. Nor did it affect lies as such because RTs would have increased for both types of lies, whereas, again, they did not. Independently from the effect of tDCS, also our statistical analysis showing that selected responses vary significantly more than unselected responses argues in favor of the general hypothesis that the 2 types of responses are modulated by different neural substrates. This conclusion is supported, despite substantial methodological differences, by recent PET findings (Abe et al. 2006) and by the existence of qualitative cognitive differences between LS and LU lies. Whereas LS lies require focusing attention on the selected pictures, LU lies do not, and the DLPFC is known to be involved in this sort of attentional control (Sakai et al. 2002). Anodal tDCS can therefore selectively impair LS responses because they rely on attentional control exerted by DLPFC. Interestingly, because anodal tDCS over the DLPFC left truthful responses unaffected, the attention mechanisms putatively involved probably do not involve working memory and are LS specific. Because none of the available functional neuroimaging studies compared LS and LU responses whether their functional anatomy differs remains unknown. LU responses probably require more complex neural processing than LS responses. This hypothesis receives support in our study from the longer RTs for LU than for LS responses before tDCS. In other words, a type of lying that is relatively fast, such as LS, may be processed almost exclusively in the DLPFC, whereas more complex lying, such as LU, may need more complex cortical processing involving other cortical areas. Anodal tDCS–induced modulation of DLPFC function might therefore affect the localized LS mechanism, but not other lying mechanisms involving different cortical areas. Alternatively, LS could be viewed as a simplified version of the pretending not to know lies (experienced events, selected pictures) and LU lies as a simplified version of the pretending to know lies (experienced events, selected pictures). Previous experiments (Abe et al. 2006) suggested a selective correlation between the DLPFC and the ACC during pretending not to know lies. Various sources point to the ACC as the neural substrate that modulates

cognitive mechanisms involved in deception, such as conflict monitoring (Botvinick et al. 2004). tDCS could therefore modulate the reciprocal interaction between DLPFC and ACC, affecting the physiological process of LS. Hence, the selective tDCS-induced effect on LS could have at least 3 possible explanations. First, tDCS could impair the attentional processes required for LS; second, LU might involve cortical areas unaffected by tDCS; and third, tDCS could modulate LS-specific interactions between the DLPFC and other cortical areas.

In conclusion, our experiments suggest that the neural processes underlying deception are complex and involve different cortical areas for different types of lies. Although our experiments open the possibility of simply and safely influencing the human will and freedom by interfering with deception, they also raise important neuroethical issues.

Notes

Conflict of Interest: None declared.

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