Neuropsychologia 86 (2016) 13–18

Contents lists available at ScienceDirect

Neuropsychologia

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

Prefrontal transcranial direct current stimulation facilitates affective flexibility

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A R T I C L E I N F O

Article history:
Received 15 November 2015
Received in revised form
26 January 2016
Accepted 23 March 2016
Available online 30 March 2016

Keywords:
Affective flexibility
Emotion regulation
Neurostimulation
Switching
Transcranial direct current stimulation

A B S T R A C T

Performance on paradigms involving switching between emotional and non-emotional task-sets (affective flexibility) predicts emotion regulation abilities and is impaired in patients with different emotional disorders. A better understanding of how neurostimulation techniques such as transcranial direct current stimulation (tDCS) influence affective switching may provide support for the improvement of rehabilitation programs. In the current study healthy volunteers received anodal tDCS over the right dorsolateral prefrontal cortex (DLPFC), the left DLPFC or sham stimulation while performing an affective-switching task. Participants had to repeat or switch between facial judgments of emotional expressions (emotional task-set) or gender (non-emotional task-set). Right tDCS resulted in faster responses in the gender task only when it followed a judgment of emotion. These effects were not observed following left tDCS. Further, switching away from emotion was easier for the right compared to left tDCS group (reduced switch costs for gender), while switching away from gender toward emotion was easier for the left compared to the right group (reduced switch-costs for emotion). In sum, tDCS over the DLPFC may modulate affective flexibility and right stimulation may be particularly helpful to facilitate disengagement from emotional task-sets. The usefulness of tDCS-trained affective switching may be further investigated on larger therapeutic protocols targeting emotional disorders.

1. Introduction

Rapid identification of emotional facial expressions is an essential, socially adaptive skill. It allows adequate response to an interlocutor during interpersonal exchanges (Kret and Ploeger, 2015) *for review*. However, being able to disengage attention from emotional features and orienting toward non-emotional information is also required in order to cope with socially distressing situations and emotional events in general (de Vries and Geurts, 2012; Genet and Siemer, 2011; Johnson, 2009). Attending to and disengaging from emotional material in a flexible manner is termed *affective flexibility* or *affective switching* (Malooly, Genet, and Siemer, 2013). This ability is associated with the use of adaptive emotion regulation strategies, such as reappraisal - the ability to cognitively re-interpret the situation and thus to modify emotional experience (Gross, 2002; Malooly et al., 2013). Affective switching ability and the frequent use of reappraisal are both predictors of lower levels of anxiety and depression (De Lissnyder et al., 2012; Johnson, 2009).

Experimental paradigms focusing on affective flexibility are good predictors of the implementation of these skills in everyday life (De Lissnyder et al., 2012; Genet and Siemer, 2011). For instance, Genet and Siemer (2011) examined the relationship between self-reported flexible adaptation to emotional events in daily life and performance on a task involving switching between categorizing affective words according to their valence or grammatical class. They found that emotional flexibility in everyday life predicted better switching abilities, as shown by lower task switch-costs. Switch-costs reflect the difference between reaction times on trials when a task is repeated and trials requiring a switch (Monsell, 2000). Further support for the clinical importance of affective switching paradigms is provided by studies showing that this ability is diminished in clinical samples characterized by difficulties in social adaptation. For example, in contrast to controls, children with autism spectrum disorders showed slower reaction times when switching from emotional to non-emotional facial features (de Vries and Geurts, 2012). This was not observed for switches occurring in the reverse direction. In a similar paradigm, patients with bipolar disorder showed greater switch-costs (higher reaction times on switch compared to non-

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http://dx.doi.org/10.1016/j.neuropsychologia.2016.03.030
0028-3932/

switch trials) than controls when gender judgment of faces followed the judgment of their emotional valence (Gul and Khan, 2014). Furthermore, affective switching not only predicts poorer flexibility in managing emotions in everyday life, but is also associated with less adaptive responses to stressful events (De Lissnyder et al., 2012).

Standard therapeutic programs targeting emotion regulation or social skills may improve affective switching in everyday life and lead to better social adaptation (Goldin et al., 2014; Ponizovsky et al., 2013; Wyman et al., 2010). Moreover, as demonstrated in the treatment of depression or rehabilitation following brain injury, effects of these standard programs may be enhanced when combined with noninvasive neuromodulation techniques, such as transcranial direct current stimulation (tDCS) (Dhaliwal et al., 2015; Meron et al., 2015; Shiozawa et al., 2014). At a neural level, tDCS modifies excitability of neurons under the targeted cortical area, increasing it with anodal (excitatory) stimulation and decreasing it with cathodal (inhibitory) stimulation (Bikson et al., 2013; Nitsche and Paulus, 2000; Tremblay et al., 2014). Boggio et al. (2015) argue that tDCS is a promising tool in the rehabilitation of social deficits. Ideally, investigation protocols should start by examining short-term effects of neurostimulaton, as observed in a single stimulation session, and move toward the investigation of more long lasting effects (repetitive stimulation or inclusion of a stimulation session in larger therapeutic protocols) (Boggio et al., 2015).

The choice of the region to be stimulated is usually based on functional neuroimaging and electrophysiological data using similar paradigms or on reported effects of previous stimulation. For instance, studies using functional imaging report bilateral activation of the dorsolateral prefrontal cortex (DLPFC) during task-switching for emotional and non-emotional material (Loose et al., 2006; Piguet et al., 2013). However, there appears to be a hemispheric difference, with the left DLPFC being preferentially activated by non-emotional tasks (Ravizza and Carter, 2008; Wendelken et al., 2012; Yoshida et al., 2010) and the right DLPFC for tasks implicating affective switching (Krug and Carter, 2012; Reeck and Egner, 2014). Consistent with neuroimaging studies, excitatory anodal tDCS applied over the left DLPFC improved switching in a paradigm using non-emotional verbal material (naming letters or digits according to specific cues) (Leite et al., 2013). Stimulating the same region, Vanderhasselt et al. (2013) found improved reaction times in a task requiring to evoke the opposite emotion to the one depicted by a face (e.g., 'sadness' when the image showed a happy face). This study did not examine switches between emotional and non-emotional tasks and did not include a control condition with right DLPFC stimulation. Performance on affective switching paradigms is known to be related to emotion regulation abilities, and these have been reported to improve following tDCS over the right DLPFC (De Lissnyder et al., 2012; Feeser et al., 2014; Genet and Siemer, 2011; Riva et al., 2015). However, none of these previous studies compared the influence of tDCS over the left and the right DLPFC on competition between emotional and non-emotional task-sets.

Here, we examined the effects of anodal-excitatory tDCS over the left and right DLPFC on (1) task repetition involving switching *within* emotional and non-emotional task-sets (e.g., from joy to anger and vice versa, and from male to female and vice versa), (2) switching *between* emotional and non-emotional tasks sets, (3) task switch-costs (reaction time differences between task-switching and task-repetition). Given the strong implication of the DLPFC in task switching we hypothesized that anodal stimulation of this region would facilitate switching processes.

2. Material and methods

2.1. Participants

Forty-five healthy volunteers (21 males, 42 right-handed), aged between 19 and 52 years (Mean=27.16, SD=6.7) participated for payment to this study. They reported no previous psychiatric or neurological disease and had normal or corrected-to-normal visual acuity. Once they agreed to participate, they were successively allocated to one of the three stimulation groups: right anodal tDCS, left anodal tDCS, or sham. Participants were blind to condition, but not the administrator. The three groups did not differ significantly regarding gender distribution ($X^2(2)=4.8$, *ns*) or age ($F(2, 42)=1.8$, *ns;* Right: *Mean*=24.5, *SD*=3.6; Left: *Mean*=28.3, *SD*=6.3; Sham *Mean*=28.6 SD=8.7). As shown in Table 1, groups did not differ regarding self-reported depressive symptoms on the *Beck Depression Inventory-2*-BDI (Beck et al., 1961) ($F(2, 41)=0.36$, *ns*), proneness to anger manifestations on the The *Spielberger trait-anger inventory*-STAXI-T 2 (Spielberger et al., 1995) ($F(2, 42)=1.24$, *ns*) or use of emotion regulation strategies on the Emotion Regulation Questionnaire-ERQ (Gross and Oliver, 2002) (*Reappraisal*: $F(2, 36)=0.49$, ns; *Suppression*: $F(2, 36)=1.25$, *ns*).

2.2. Material and procedures

The study was approved by the local ethics committee. In a single experimental session, participants signed the informed consent, filled out a safety-screening health questionnaire (in order to verify suitability to tDCS) and completed an affective switching task under one of the three stimulation conditions. They then completed a demographic questionnaire and self-report psychological scales.

Table 1
Mean reaction times during the affective switching task and total scores on self-reported questionnaires

	Right tDCS Emotion	Gender	Left tDCS Emotion	Gender	Sham Emotion	Gender
Task-Switch	*gender-emotion*	*emotion-gender*	*gender-emotion*	*emotion-gender*	*gender-emotion*	*emotion-gender*
Block 1	746 (107)	670 (78)	740 (118)	718 (103	775 (143)	735 (136)
Block 2	695 (75)	667 (69)	686 (134)	699 (142)	734 (142)	719 (152)
Task-repetition	*emotion-emotion*	*gender-gender*	*emotion-emotion*	*gender-gender*	*emotion-emotion*	*gender-gender*
Block 1	711 (76)	681 (80)	743 (119)	700 (105)	767 (132)	742 (157)
Block 2	703 (72)	666 (81)	706 (131)	684 (130)	769 (200)	705 (146)
Questionnaires						
Beck	8.0 (8.59)		7.07 (4.76)		5.93 (5.82)	
STAXI-T	19.8 (3.34)		17.7 (3.64)		18.7 (4.17)	
ERQ-Reappraisal	5.04 (0.74)		4.72 (0.97)		4.81 (0.73)	
ERQ-Suppression	3.75 (1.08)		3.64 (1.28)		3.06 (1.08)	