



## The effect of transcranial direct current stimulation of the prefrontal cortex on implicit self-esteem is mediated by rumination after criticism



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### ABSTRACT

It has been proposed that a crucial link between cognitive (i.e., self-schemas) and biological vulnerability is prefrontal control. This is because decreased control leads to impaired ability to inhibit ruminative thinking after the activation of negative self-schemas. However, current evidence is mainly correlational. In the current experimental study we tested whether the effect of neurostimulation of the dorsolateral prefrontal cortex (DLPFC) on self-esteem is mediated by momentary ruminative self-referential thinking (MRST) after the induction of negative self-schemas by criticism. We used a single, sham-controlled crossover session of anodal transcranial Direct Current Stimulation (tDCS) applied to the left DLPFC (cathode over the right supraorbital region) in healthy female individuals. After receiving tDCS/sham stimulation, we measured MRST and exposed the participants to critical audio scripts, followed by another MRST measurement. Subsequently, all participants completed two Implicit Relational Assessment Procedures to implicitly measure actual and ideal self-esteem. Our behavioral data indicated a significant decrease in MRST after real but not sham tDCS. Moreover, although there was no immediate effect of tDCS on implicit self-esteem, an indirect effect was found through double mediation, with the difference in MRST from baseline to after stimulation and from baseline to after criticism as our two mediators. The larger the decrease of criticism induced MRST after real tDCS, the higher the level of actual self-esteem. Our results show that tDCS can influence cognitive processes such as rumination, and subsequently self-esteem, but only after the activation of negative self-schemas. Rumination and negative self-esteem characterize different forms of psychopathology, and these data expand our knowledge of the role of the prefrontal cortex in controlling these self-referential processes, and the mechanisms of action of tDCS.

Excessive engagement in self-focused thinking, such as rumination, has a variety of negative consequences (Mor & Winquist, 2002). Moreover, it has been demonstrated that the repetitive and perseverative characteristics of ruminative thinking are a transdiagnostic risk factor for several mental disorders (e.g., Watkins, 2008). Although ruminative thinking is mostly investigated as a trait characteristic, self-referential thoughts fluctuate continuously, even in healthy individuals (Moberly & Watkins, 2008). Interestingly, the harmful effects of rumination seem to be related to its evaluative and judgmental nature (Rude, Maestas, & Neff, 2007), linking rumination to self-esteem.

In recent years, information-processing approaches have been used to investigate the underlying mechanisms of self-referent perseverative thinking styles such as rumination. Based on the integration of findings

from experimental psychopathology and cognitive neuroscience research, it has been proposed that decreased prefrontal control is at the core of prolonged processing of self-referent thoughts (Koster, De Lissnyder, Derakshan, & De Raedt, 2011). Neuroimaging studies have indicated that a functional balance between ventral (ventral anterior cingulate cortex, ACC) and dorsal regions in the brain (dorsolateral prefrontal cortex-DLPFC; dorsal ACC) is necessary for maintaining homeostatic emotional control (Ochsner & Gross, 2008; Wager, Davidson, Hughes, Lindquist, & Ochsner, 2008). Furthermore, the results of many studies indicate that the DLPFC initiates emotion regulation by causing inhibition of the amygdala (e.g., Siegle, Thompson, Carter, Steinhauer, & Thase, 2007), and rumination has been linked to DLPFC activity (Vanderhasselt, Kuehn, & De Raedt, 2011).

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In line with this, increasing vulnerability to respond in a maladaptive way to stressors has been conceptualized as a vicious circle in which self-focused rumination can act as a stressful personally relevant event that triggers the activation of negative schemas. This would reinforce further ruminative elaboration, which in turn fuels the development of negative self-views (i.e., self-esteem). Within this framework, it is proposed that the crucial link between cognitive (i.e. self-schemas) and biological vulnerability is prefrontal control, because decreased inhibitory control leads to impaired ability to stop negative elaborative processes, such as rumination (De Raedt & Koster, 2010). In the present study, we sought to test the mechanisms of this framework in healthy individuals, investigating whether the effect of increased DLPFC activity on self-esteem is mediated by rumination. Given that, in healthy individuals, routine self-focused ruminative thinking may not trigger automatically negative self-schemas, we examined these processes after exposure to criticism.

Correlational studies have shown evidence of a link between negative self-schemas and rumination (Leahy, 2002), and ruminative thinking and decreased prefrontal cognitive control (for an overview, see De Raedt, Vanderhasselt, & Baeken, 2015). Experimental research is now necessary to establish causal mechanisms. Neurostimulation of the left prefrontal cortex (using tDCS) has been found to reduce state rumination via a beneficial change in cognitive control processes (Vanderhasselt, Brunoni, Loeys, Boggio, & De Raedt, 2013). This is in line with the observation that prefrontal regions have been associated extensively with emotional regulatory processes (Cerqueira, Almeida, & Sousa, 2008; Davidson et al., 2002). Moreover, as noted in the review of Remue, Baeken, and De Raedt (2016) a single neurostimulation session over the prefrontal cortex does not affect mood in healthy participants. This excludes the possible confound of mood changes on rumination and self-esteem.

To trigger negative self-referent schemas, we used personal criticisms. Various studies have demonstrated a link between sensitivity to criticism and psychopathology, such as depression (e.g., Burcusa & Iacono, 2007). In people vulnerable to depression there is also a link between criticism and decreased prefrontal activity. Indeed, Hooley and colleagues have demonstrated that even after full recovery from an episode of major depression, neural responding to criticism did not normalize. That is, when individuals who have recovered from depression are exposed to criticism, they demonstrate decreased reactivity in the DLPFC compared to never-depressed individuals (Hooley, Gruber, Scott, Hiller, & Yurgelun-Todd, 2005; Hooley et al., 2009).

Research has further shown that being criticized triggers self-referential thoughts and feelings that need to be regulated to prevent maladaptive emotional responses from occurring (e.g., Vanderhasselt, Remue, Ng, Mueller, & De Raedt, 2015). Being criticized is a distressing experience for many. It activates self-conscious emotions (e.g., feeling hurt) and can have a negative impact on self-worth. Criticism has a detrimental impact on cognitive processing and thinking styles such as rumination (e.g., Kaiser, Andrews-Hanna, Metcalfe, & Dimidjian, 2015; Saffrey & Ehrenberg, 2007), and can have an effect on self-esteem (e.g. Weisbuch, Sinclair, Skorinko, & Eccleston, 2009). For these reasons we explored the occurrence of ruminative self-referential thoughts during rest periods before and after criticism. Participants were asked to rest without being given any specific task. This is known to result in a stream of undirected thinking patterns. Momentary ruminative self-referential thinking (MRST) was assessed during this period using a short self-report questionnaire. MRST refers to a temporary cognitive thought pattern that is highly dependent on situational cues but that is independent of mood.

Although healthy individuals may be able to regulate (via cognitive control) criticism-induced thoughts and emotions to protect their self-esteem (and maintain emotional well-being), according to cognitive theories, patients with affective disorders would be expected to show decreased self-esteem. Importantly, it has been shown that self-esteem is not

only a correlate but also a vulnerability factor for disorders such as depression (Orth & Robins, 2013). Most research on self-esteem has employed self-report measures, which are susceptible to a variety of response biases such as social desirability and self-presentation. However, cognitive models of depression assume that self-related schemas are not always consciously accessible and thus are not invariably amenable to self-report (Beck, Rush, Shaw, & Emery, 1979; Young, 1994). This raises the question of whether the use of self-report measures can provide the most meaningful information about such schemas.

To overcome these limitations, a number of alternative procedures have recently emerged that reduce the participant's ability to control their responses and operate in such a way that they do not depend on introspective access to the psychological content of interest. Whereas self-report measures of self-esteem can be classified as explicit measures that capture non-automatic instances of self-evaluation (e.g., self-evaluations that occur when participants have ample time and resources to reflect or have the intention to evaluate the self), implicit measures of self-esteem register more spontaneous, automatic self-evaluations (e.g., self-evaluations that occur quickly or when participants do not have the intention to evaluate the self; see De Houwer, Teige-Mocigemba, Spruyt, & Moors, 2009). In recent years several studies have investigated the implicit positivity bias in (remitted) depressed patients and healthy controls (e.g., De Raedt, Schacht, Franck, & De Houwer, 2006; Gemar, Segal, Sagrati, & Kennedy, 2001). Extending this work, De Raedt and colleagues (Remue, De Houwer, Barnes-Holmes, Vanderhasselt, & De Raedt, 2013; Remue, Hughes, De Houwer, & De Raedt, 2014) have used the implicit relational assessment procedure (IRAP, see Barnes-Holmes, Barnes-Holmes, Stewart, & Boles, 2010) to test the idea that self-esteem might be broken down into actual and ideal self-esteem, with different patterns specifically related to depressive symptoms (dysphorics versus non-dysphorics). Results have shown higher levels of ideal self-esteem versus actual self-esteem in dysphorics, with a reversed pattern in non-dysphorics (Remue et al., 2013). Interestingly, never depressed individuals show decreases in implicit self-esteem following rumination relative to distraction (Roberts, Porter, & Vergara-Lopez, 2016).

In this study we investigated the impact of DLPFC activity on MRST and examined how this affects a person's self-esteem (both actual and ideal self). We used neurostimulation to experimentally manipulate DLPFC activity, given that this area is known for its regulatory function of coping with negative cognitions. A variety of studies have shown that non-invasive brain stimulation over the left DLPFC can be effective in reducing depressive symptoms in the short term in clinically depressed populations (for an overview, see De Raedt et al., 2015).

To experimentally test if our experimental manipulation would lead to a greater control over self-referential processes, and thus decrease rumination leading to positive effects on self-esteem, we applied anodal tDCS to the DLPFC (cathode over the right supraorbital region). tDCS consists of the application of a weak, direct electric current through electrodes positioned over the scalp, which are able to reach the neuronal tissue and induce polarization-shifts on the resting membrane potential (Brunoni et al., 2011). In previous studies it has been demonstrated that tDCS of the left DLPFC enhances cognitive processes, both for non-emotional (e.g., Fregni et al., 2005; Leite, Carvalho, Fregni, & Gonçalves, 2011; Mulquiney, Hoy, Daskalakis, & Fitzgerald, 2011) and emotional processes (Vanderhasselt, De Raedt et al., 2013; Wolkenstein & Plewnia, 2013). Importantly, the after-effects of tDCS can last up to one hour (Nitsche & Paulus, 2001; Nitsche et al., 2003); this creates opportunities for longer experimental protocols. We investigated both the direct effect of tDCS on MRST, as well as the mediating effect of criticism induced MRST on an implicit measure of self-esteem, conceptualized as actual and ideal self-esteem.

In line with former studies, we expected a decrease of MRST after anodal tDCS. Moreover, we hypothesized that in a sample of healthy female individuals, the effect of tDCS on self-esteem would be mediated by ruminative self-referential thinking after the activation of negative

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