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When Anger Leads to Rumination: Induction of Relative Right Frontal Cortical Activity With Transcranial Direct Current Stimulation Increases Anger-Related Rumination

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Abstract

Anger is associated with various responses. Research on the neuroscience of anger has revealed that greater left than right frontal cortical activity is associated with angry approach-oriented responses, such as aggression, whereas greater right than left frontal cortical activity is associated with inhibited angry responses mixed with anxiety. In the current research, we extended these past studies by manipulating asymmetric frontal cortical activity using transcranial direct current stimulation and assessing its influence on ruminative responses to an interpersonal insult. Results revealed that self-reported rumination was greatest for participants who received a manipulated increase in relative right frontal cortical activity compared with those who received either a manipulated increase in relative left frontal cortical activity or sham stimulation. Taken together with past findings, the current results suggest that anger associated with greater relative left frontal cortical activity predicts approach-oriented aggressive action, whereas anger associated with greater relative right frontal cortical activity predicts inhibited rumination.

Keywords

rumination, anger, frontal cortex, approach motivation, transcranial direct current stimulation, motivation, cognitive processes, frontal lobe, emotions, electrophysiology

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From an evolutionary perspective, the survival of any organism is contingent on systems of approach and avoidance. One brain region (among many) that differentiates approach from avoidance is the frontal cortex, in which greater left than right frontal cortical activity (relative left frontal cortical activity) has been related to approach motivation and greater right than left frontal cortical activity (relative right frontal cortical activity) has been related to avoidance motivation or inhibition (Harmon-Jones, Gable, & Peterson, 2010; Wacker, Chavanon, Leue, & Stemmler, 2008). Despite the integration of affect and cognition in the frontal cortex, cognitive variables related to frontal asymmetries have largely been ignored in the literature on motivation. Rumination is a cognitive process that has been associated with frontal cortical activity, but a clear asymmetric pattern for this process has not been determined. This is important because rumination has been associated with indices of greater relative right frontal cortical activity (e.g., depression) as well as indices of greater relative left frontal cortical activity (e.g., aggression). By using transcranial direct current stimulation (tDCS), we aimed in the current research to directly manipulate asymmetry in frontal brain activity and thereby directly test the causal role of asymmetric activity on rumination.

Studies in which brain activity is directly manipulated and psychological outcomes are measured allow researchers to draw causal inferences about behavior (Schutter, van Honk, & Panksepp, 2004). Employing repetitive transcranial magnetic stimulation, van Honk and Schutter (2006) found that inhibiting the left prefrontal cortex impairs the processing of angry

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facial expressions (also see van Honk, Schutter, d'Alfonso, Kessels, & de Haan, 2002).

A recent addition to the neuroscientist's toolbox, tDCS is a safe and noninvasive neuromodulation technique that influences cortical activity by means of a weak electrical current between two electrodes (for a review, see Nitsche et al., 2008). It is ideal for studies of asymmetric brain function, as one electrode (anodal) causes an increase in cortical excitability, whereas the other electrode (cathodal) causes a decrease in cortical excitability (Nitsche & Paulus, 2000). These characteristics make this technique well suited to studying the influence of frontal asymmetry on anger-related responses.

Recently, we used tDCS to manipulate asymmetric frontal cortical activity to examine its effect on anger and aggression in response to an interpersonal insult (Hortensius, Schutter, and Harmon-Jones, 2012). Results indicated that after receiving tDCS to increase relative left frontal cortical activity, individuals behaved more aggressively toward other participants when they were angry.

Left frontal cortical activity is greater than right frontal cortical activity when approach or offensive aggression opportunities are available, as illustrated in the study conducted by Harmon-Jones, Sigelman, Bohlig, and Harmon-Jones (2003). They examined greater relative left frontal cortical activity in response to an anger-inducing situation. The anger manipulation caused significantly more relative left frontal activity when individuals believed they could act on their anger compared with when they believed they could not (also see Harmon-Jones, Lueck, Fearn, & Harmon-Jones, 2006).

Although anger is often associated with approach, that is not always the case. When the expression of anger is physically impossible or socially inappropriate, individuals may be motivated to inhibit rather than act on their anger. Zinner, Brodish, Devine, and Harmon-Jones (2008) explored this idea by examining asymmetric frontal brain activity and self-reported emotions in an interracial interaction. Such a situation evokes anger in some individuals who are opposed to societal pressure to eliminate prejudice, but it also evokes anxiety and possibly motivation to inhibit anger. Consistent with predictions, in this situation, results showed that greater relative right frontal cortical activity was associated with higher anger.

During anger-evoking situations in which individuals may be motivated to inhibit their angry behavior, rumination may occur. Broadly defined, rumination is an automatic cognitive process in which thoughts are repetitious and difficult to inhibit, and there is a passive focus on the symptoms of distress (Nolen-Hoeksema, 1991, 2000; Wade, Vogel, Liao, & Goldman, 2008). Consistent with the idea of rumination being related to behavioral inhibition, findings have shown that trait rumination relates more strongly to trait anger toward oneself than to trait anger toward other people (Martin & Dahlen, 2005) and that trait rumination relates to behavioral-inhibition sensitivity but not to behavioral-approach sensitivity (Denson, Pedersen, & Miller, 2006).

To date, no studies have directly linked rumination to increased frontal cortical activity in either the left or the right hemisphere. Some functional MRI (fMRI) studies have suggested a relationship between rumination and activity in a number of frontal regions (e.g., dorsal anterior cingulate, insula, medial frontal gyrus, lateral middle frontal gyrus; Denson, Pedersen, Ronquillo, & Nandy, 2009; Ray et al., 2005). However, these studies did not specifically test for asymmetric patterns of activity as recommended by Berkman and Lieberman (2010). Moreover, fMRI data, which measures blood flow and oxygenation, do not always relate to electrical measures of brain activity (for a review, see Carver & Harmon-Jones, 2009).

Other studies have suggested that rumination may be associated with greater relative right frontal cortical activity because depression is related to greater relative right frontal activity (Heller, Etienne, & Miller, 1995), and depression has been linked with rumination (Nolen-Hoeksema, 2000). These results are consistent with the idea that rumination may be associated with greater relative right frontal activity.

However, a separate line of research suggests that rumination may be associated with greater relative left frontal cortical activity. Bushman (2002) found rumination to be associated with self-reported anger, which is associated with approach motivation and greater relative left frontal cortical activity (Carver & Harmon-Jones, 2009; Harmon-Jones, Vaughn-Scott, Mohr, Sigelman, & Harmon-Jones, 2004). Additionally, rumination can intensify anger and lead to aggression (e.g., Bushman, Bonacci, Pedersen, Vasquez, & Miller, 2005; Pedersen et al., 2011).

Thus, two competing hypotheses can be produced and tested. Following the rumination-depression literature, we would predict that an increase in relative right frontal cortical activity would result in more rumination after anger induction compared with an increase in relative left frontal cortical activity or sham stimulation. In contrast, following the rumination-aggression literature, we would predict the opposite: that an increase in relative left frontal cortical activity would result in more rumination after anger induction compared with an increase in relative right frontal cortical activity or sham stimulation. Our goal in the current research was to test these competing predictions by manipulating asymmetric frontal cortical activity using tDCS and examining its effects on rumination in response to anger induction.

Method

Participants

Participants were 115 healthy, right-handed undergraduates (73 females, 42 males) who voluntarily participated in a double-blind sham-controlled between-subjects design in exchange for course credit. No participants showed contraindications for noninvasive brain stimulation (Nitsche et al., 2008), such as psychiatric or neurological history, damaged skin tissue, and use of medications (with the exception of

women using oral contraceptives). Participants were excluded because of suspicion about the deception procedures ($n = 21$) or technical problems ($n = 4$). As a result, 90 participants (60 female, 30 male) were left for analysis. Written consent was obtained, and participants were naive to both the aim of the study and tDCS.

Procedure

Participants were led to believe that they were participating in an experiment on impression formation as it relates to writing and personality (e.g., Harmon-Jones & Sigelman, 2001). On arrival to the lab, participants completed a consent form, a handedness questionnaire (Chapman & Chapman, 1987), a safety screening, measures of behavioral approach and inhibition (Carver & White, 1994), and a self-report emotions scale that asked them to rate how angry, sad, and happy they felt using words related to those emotions (1 = *very slightly/not at all* to 5 = *extremely*; see Harmon-Jones, Harmon-Jones, Abramson, & Peterson, 2009). Baseline anger was low ($M = 1.32$, $SD = 0.53$), and no differences were found among conditions in terms of baseline emotions and behavioral approach and inhibition ($ps > .10$).

Participants were led to believe that they had been randomly selected to write an essay on a current issue of their choice (e.g., abortion policy, gay marriage) while another participant had been randomly assigned to read and evaluate their essay. After the participant spent 10 min writing the essay, the experimenter took it to an adjacent room for the other participant to evaluate. In reality, no other participant existed.

Next, participants received tDCS for 15 min. After 10 min of stimulation, the experimenter ostensibly went into an adjacent room to retrieve the feedback from the other participant. In fact, the essay feedback form had been created by the researchers, and each participant received the same feedback, so that anger could be induced. The feedback form was presented to the participant in an envelope, and it contained ratings of the participant on a variety of characteristics (e.g., intelligence, respectability) on a 9-point scale on which higher ratings indicate more positive impressions. The ratings were negative and varied between 2 and 4. In a section for additional comments, the "other participant" had written, "This essay on [the topic of the participant's essay] is not good. I can't believe an educated person would think like this. I hope this person learns something at A&M."

After the participant read the feedback and the tDCS finished, the participant was told that he or she needed to complete a last set of questionnaires. These questionnaires included a state-rumination measure, a thought-listing procedure (Cacioppo & Petty, 1981), and a self-reported emotions instrument. During the procedure, there was no possibility of retaliation or other aggressive reactions. The participant never saw the other (ostensible) participant and never had an expectation of meeting him or her.

tDCS

The same stimulation parameters used here were used in a separate sample in another study (Hortensius et al., 2012). A battery-driven Magstim Eldith DC-Stimulator Plus (neuroConn, Ilmenau, Germany) with 5 cm × 7 cm conductive-rubber electrodes was used. Stimulation lasted for 15 min, with a current intensity of 2 mA (maximum current density: 0.057 mA/cm^2, total charge: 0.0512 C/cm^2, ramp-up and ramp-down: 5 s each). A bipolar montage was used, and electrodes were placed in wet sponges saturated with electrode gel and fixed to the scalp over left (F3) and right (F4) prefrontal regions (according to the 10-20 EEG system).

Both experimenter and participants were blind to the tDCS conditions, which were controlled by a separate investigator. Each participant was randomly assigned to one of three conditions: increase in relative left frontal cortical activity (anodal electrode over F3, cathodal electrode over F4; $n = 29$), increase in relative right frontal cortical activity (cathodal electrode over F3, anodal electrode over F4; $n = 28$), or sham stimulation ($n = 33$). In the sham-stimulation condition, all settings except the stimulation duration (ramp-up: 5 s; stimulation: 30 s; ramp-down: 5 s) were identical to settings in the other conditions. This is a reliable method of sham stimulation that does not result in any aftereffects (Gandiga, Hummel, & Cohen, 2006). Participants tolerated tDCS well, sham stimulation was successful, and there were no differences among groups when participants were asked to guess whether they received active or sham stimulation, $\chi^2(2, N = 90) = 1.97$, $p > .37$.

State-rumination measure

A 10-item measure of state rumination was created. Participants rated on a 7-point scale how the feedback on their essay made them feel (e.g., "What words below best describe how you are thinking about the feedback you received?"; 1 = *at ease with it*, 7 = *worked up about it*). They also used a 7-point scale to rate their impressions of the person evaluating them. Items were derived and adapted from Trapnell and Campbell's (1999) rumination subscale; Fenigstein, Scheier, and Buss's (1975) Private Self-Consciousness scale;[1] and trait measures of angry rumination (e.g., Denson et al., 2006). See the Supplemental Material available online for the state-rumination measure.

To supplement and validate this newly developed instrument, we also asked participants to complete Cacioppo and Petty's (1981) thought-listing procedure, in which participants wrote down any thoughts they had after reading their essay feedback. A set of two independent coders, blind to experimental condition and hypotheses, coded the thoughts listed as either ruminative or not ruminative. There was a high degree of agreement between the two raters (Cronbach's $\alpha = .91$), and as a result, a composite score for number of ruminative thoughts was created.

Results

Preliminary analyses

To address the validity of our new measure of state rumination, we correlated the number of ruminative thoughts listed[2] with scores on the state-rumination measure. Consistent with expectations, results showed a positive association between the two, $r(74) = .53$, $p < .001$. To further validate the measure, we examined its relationship to Carver and White's (1994) Behavioral Inhibition Sensitivity (BIS) and Behavioral Approach Sensitivity (BAS) scales. Because rumination is posited to be an inhibition-oriented cognitive process, we expected self-reported state rumination to correlate positively with BIS scores. Results were consistent with these expectations, $r(90) = .36$, $p < .001$. Self-reported rumination and total BAS scores were not significantly correlated, $r(90) = -.11$, $p = .28$. Further examination of the BAS subscales revealed a marginally significant, negative correlation between the Drive subscale and our self-report measure of rumination, $r(90) = -.19$, $p = .069$; however, the BAS Fun Seeking and Reward Responsiveness subscales were not significantly correlated with rumination, rs = −.14 and .13, respectively, ps = .17 and .23, respectively. In addition, the rumination measure also showed good internal consistency (Cronbach's $\alpha = .79$). These results support both the validity and reliability of this new measure of state rumination.

Self-reported anger at baseline was low and did not differ between conditions, $F(2, 87) = 0.31$, $p = .73$. However, the insult effectively increased anger for all conditions. This effect was revealed in a 3 (tDCS condition: increase relative left frontal cortical activity vs. increase relative right frontal cortical activity vs. sham; between subjects) × 2 (anger: baseline vs. after insult; within subjects) mixed analysis of variance. Postinsult anger was significantly elevated above baseline in all three conditions, $F(1, 87) = 104.35$, $p < .0001$, $\eta_p^2 = .55$. There was no main effect of tDCS condition on anger, $F(2, 87) = 0.83$, $p = .44$, and the interaction between the two variables was not significant, $F(2, 87) = 2.19$, $p \geq .12$; these findings were consistent with previous research (Hortensius et al., 2012). Additional analyses can be found in the Supplemental Material.

Main analyses

In the condition in which relative right frontal cortical activity was increased, participants reported more rumination than in the condition in which relative left frontal cortical activity was increased or in the sham-stimulation condition (see Fig. 1a). This effect was revealed in a significant effect of tDCS condition on self-reported rumination, $F(2, 87) = 5.37$, $p = .006$, $\eta_p^2 = .11$.

The same pattern was observed for the number of ruminative thoughts, with a significant main effect of tDCS condition, $F(2, 71) = 3.39$, $p = .039$, $\eta_p^2 = .09$. In the condition in which relative right frontal cortical activity was increased, participants reported more ruminative thoughts than in the condition in which relative left frontal cortical activity was increased or in the sham-stimulation condition (see Fig. 1b). These results are consistent with the hypothesis based on the rumination-depression literature.

Discussion

A manipulated increase in relative right frontal cortical activity caused greater state rumination than did a manipulated increase in relative left frontal cortical activity and sham stimulation. In the current research, we effectively used a novel technique, tDCS, to manipulate asymmetric frontal brain activity and examined its effect on anger and rumination in response to an interpersonal insult. Although much past research has correlated asymmetric frontal cortical activity with emotional and motivational variables in emotion-related research, few researchers have manipulated this pattern of cortical activity, and few have examined this motivational pattern of cortical activation on cognitive responses (e.g., Gray, Braver, & Raichle, 2002) despite the cognitive-affective integration of the frontal cortex (Pessoa, 2008). The present research fills this void and is the first to show a causal relation between relative right frontal cortical activity and rumination after an interpersonal insult. Together with previous research (Hortensius et al., 2012), the present study shows the feasibility of using the combination of tDCS and a social-psychological manipulation, thereby expanding the social-neuroscientific toolbox with a novel tool that allowed the direct manipulation of cortical activity.

The findings are consistent with results reported in an extensive literature implicating rumination in depression and related processes. However, there is also a body of research linking rumination to aggression. For example, Denson, Pedersen, Friese, Hahm, and Roberts (2011) showed that rumination increased aggression and state rumination mediated the relationship between trait rumination and aggression. Rumination may cause individuals to hold on to their anger for long periods of time. Individuals who ruminate may let their anger fester rather than letting it diminish. While individuals ruminate or hold on to their anger, they are typically not behaving (or may actually be inhibiting their behavior). This would explain why angry rumination relates positively with behavioral-inhibition sensitivity at the trait level (Denson et al., 2006). However, when an opportunity for aggression emerges, individuals who have been holding on to their anger may suddenly react with heightened aggression, which may be driven by an approach-oriented motivation at the time. Thinking about the research on rumination in this manner is one way of reconciling our work with the aggression-rumination literature.

Two implications emerge from the current research. First, by using tDCS to manipulate brain activity, we were able to begin to understand one possible underlying physiological cause of ruminative reactions to anger-producing provocations. Second, the current research sheds light on the role of relative right frontal cortical activity in motivational

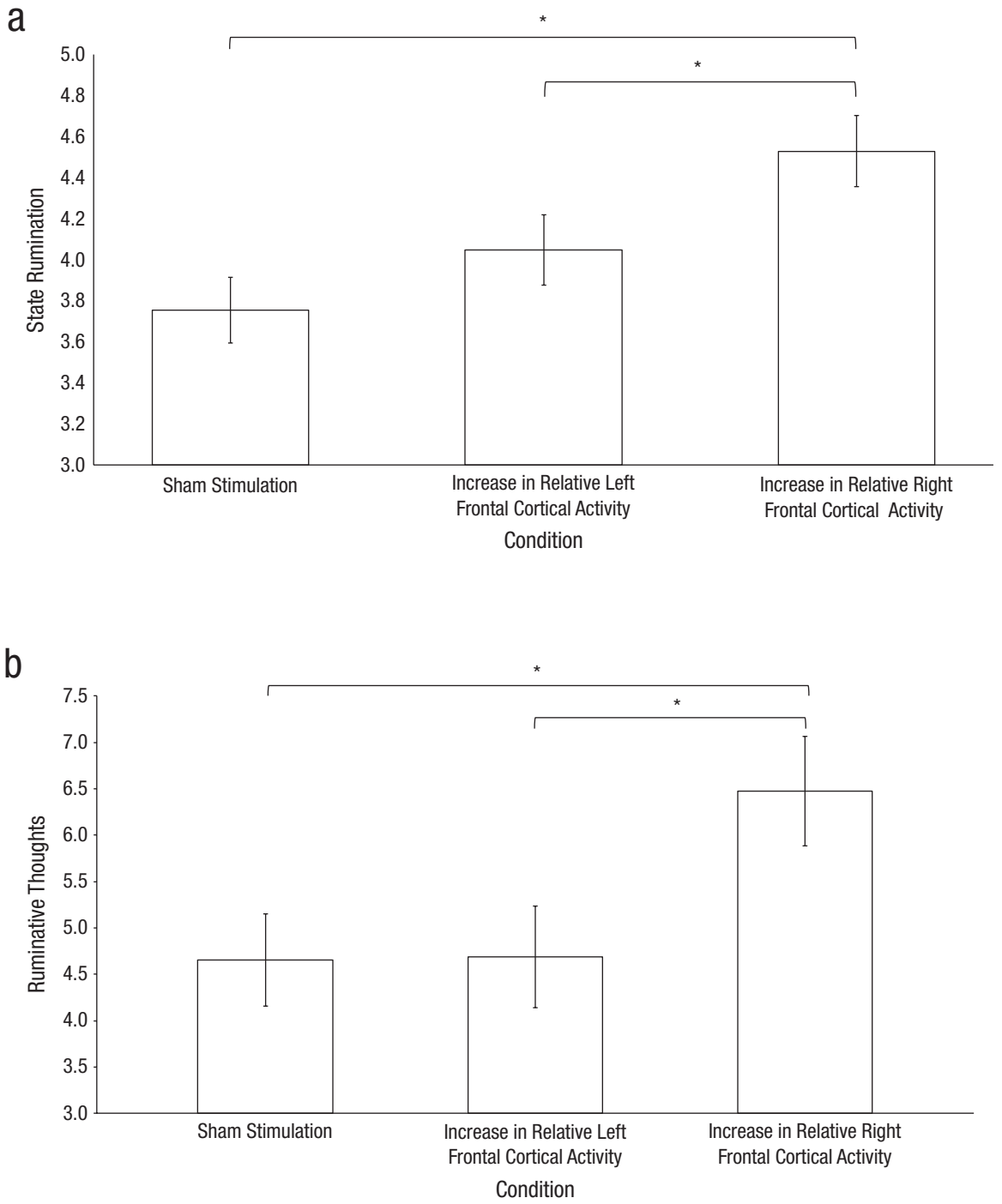

Fig. 1. Mean level of state rumination (a) and mean number of ruminative thoughts (b) as a function of the type of transcranial direct current stimulation participants received. An asterisk indicates a significant difference between conditions ($p < .05$). Error bars show standard errors.

processes. Whereas past work on asymmetric frontal cortical activity has implicated the right frontal cortex in avoidance motivation, the present results suggest that it may be involved in behavioral inhibition. Recall that rumination was positively associated with BIS scores. This association suggests that anger was felt by participants but it was not expressed—instead it was inhibited. Taken together, these results suggest that relative right frontal cortical activity may be more linked to inhibition than to avoidance (consistent with the findings of Wacker et al., 2008), though more research is needed to distinguish these closely related concepts in human research.[3]

Rumination is a clear example of the emotion-cognition integration of the prefrontal cortex. By showing that relative right frontal cortical activity causes more rumination than

relative left frontal cortical activity does, the current research generates two sets of questions to be addressed by future research. First, given that the subdivisions of the prefrontal cortex have been shown to have functional differences, which of those subdivisions are responsible for the effect in the current study? Previous fMRI research has suggested a relationship between rumination and activity in a number of regions (e.g., dorsal anterior cingulate, insula, medial frontal gyrus, lateral middle frontal gyrus; Denson et al., 2009; Ray et al., 2005); however, these studies did not specifically test for asymmetric patterns of activity as recommended by Berkman and Lieberman (2010). Future research using tDCS in conjunction with neuroimaging measures should be conducted to address questions about underlying structures that are affected.

A second question is what does the effect mean processwise? Does increasing relative right frontal cortical activity increase rumination, interfere with the habituation of negative thoughts, or increase general inhibition of prepotent responses, which might then lead to rumination? Because activity in the right inferior frontal gyrus and other areas of the right ventrolateral prefrontal cortex is linked with inhibitory processes (Aron, Robbins, & Poldrack, 2004; Levy & Wagner, 2011), we suspect that tDCS activation of right frontal cortex may increase inhibition, which then increases rumination.

In this study, we successfully manipulated asymmetric frontal cortical activity to cause a change in abstract socioemotional behavior in humans—rumination. Causal manipulations of human neural processes are extremely rare. Techniques such as tDCS should receive special attention because they allow researchers to make more refined, precise statements about the causal relationship between neural activity and psychological processes.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

Notes

1. Fenigstein, Scheier, and Buss's (1975) Private Self-Consciousness scale was used in scale development because it was recommended by other rumination researchers and used in development of the angry-rumination subscale of the Displaced Aggression Questionnaire (Denson, Pedersen, & Miller, 2006).

2. The number of ruminative thoughts was inserted into the study after data collection began. As a result, the sample size was lower for all analyses using this procedure.

3. We suggest that these concepts are closely related in human research because the same motivational system may underlie both responses, because inhibition may quickly transform into withdrawal behavior, and because the BIS questionnaire contains items that assess withdrawal.

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When anger leads to rumination: induction of relative right frontal cortical activity with transcranial direct current stimulation increases anger-related rumination

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Supplemental Online Materials

Include:

- Supplemental Results
- State Rumination Measure

Supplemental Results

The effect of tDCS on anger was not significant, but a reviewer asked us to conduct follow-up analyses. Results revealed that tDCS to increase relative right frontal cortical activity (M = 2.71, SD = .88) did not differ from the tDCS to increase relative left frontal cortical activity condition, $t(55) = .69$, $p = .49$. tDCS to increase relative right frontal cortical activity (M = 2.71, SD = .88) caused marginally more post-insult anger than did the sham stimulation condition (M = 2.22, SD = 1.22), $t(59) = 1.78$, $p = .08$. The sham stimulation condition did not differ from the tDCS to increase relative left frontal cortical activity condition (M = 2.53, SD = 1.11), $t(60) = 1.05$, $p = .30$.

State Rumination Measure

We created a measure of state rumination designed to measure reactions to interpersonal insults for use in this study. Other measures ask about rumination in a manner that could lead to suspicion about the interpersonal insult and/or demand (e.g., Wade et al., 2008). As a result, the items in our measure are subtle enough to be used in deception research.

State Rumination Measure

Directions: Please rate each of the following items in terms of how you were thinking about the feedback you received. Please choose a number, 1 through 7.

1. What words below best describe how you are thinking about the feedback you received?

It gave me cause to be proud of myself	1	2	3	4	5	6	7	It gave me cause to scrutinize myself

2. What words below best describe how your feedback made you feel?

Inattentive to my inner feelings	1	2	3	4	5	6	7	Attentive to my inner feelings

3. What words below best describe how the essay feedback affected you?

It gave me no cause to self-reflect	1	2	3	4	5	6	7	It made me reflect about myself

4. How much time have you spent thinking about how you performed on the essay task?

None. It's over and done with	1	2	3	4	5	6	7	A lot. It's really on my mind

5. What words below best describe how you are thinking about your essay performance?

It's easy for me to stop thinking about how I performed	1	2	3	4	5	6	7	It's hard for me to stop thinking about how I performed

6. What words below best describe how you are thinking about the feedback you received?

At ease with it	1	2	3	4	5	6	7	Worked up about it.

7. What words below best describe how you are thinking about the person who evaluated your essay?

I'd like to befriend this person	1	2	3	4	5	6	7	I'd like to get back at this person

8. What words below best describe your desire to meet the person who evaluated your essay?

I would very much like to avoid this person	1	2	3	4	5	6	7	I would very much like to confront this person

9. What words below best describe your future interaction (IF YOU WERE TO HAVE ONE) with the person who evaluated your essay?

I would like to thank them for the feedback	1	2	3	4	5	6	7	I would like to give them "a piece of my mind"

10. Sometimes people replay their interactions with others in their minds even when they don't see them face to face. How frequently have you replayed you interaction with the other subject in your mind?

Not at all	1	2	3	4	5	6	7	Very frequently