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When anger leads to aggression: induction of relative left frontal cortical activity with transcranial direct current stimulation increases the anger–aggression relationship

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The relationship between anger and aggression is imperfect. Based on work on the neuroscience of anger, we predicted that anger associated with greater relative left frontal cortical activation would be more likely to result in aggression. To test this hypothesis, we combined transcranial direct current stimulation (tDCS) over the frontal cortex with interpersonal provocation. Participants received insulting feedback after 15 min of tDCS and were able to aggress by administering noise blasts to the insulting participant. Individuals who received tDCS to increase relative left frontal cortical activity behaved more aggressively when they were angry. No relation between anger and aggression was observed in the increase relative right frontal cortical activity or sham condition. These results concur with the motivational direction model of frontal asymmetry, in which left frontal activity is associated with anger. We propose that anger with approach motivational tendencies is more likely to result in aggression.

Keywords: Aggression; anger; frontal cortex; approach motivation; transcranial direct current stimulation

INTRODUCTION

But anger is problematic above all other negative affects for its social consequences... my anger... threatens violence for you, your family, your friends, and above all for our society. Of all the negative affects it is the least likely to remain under the skin of the one who feels it, and so it is just that affect all societies try hardest to contain within that envelope under the skin... (Tomkins, 1991, p. 111).

This eloquent quotation by Sylvan Tomkins, the grandfather of emotions research, suggests a direct correlation between angry experience and aggressive behavior. Some research has found support for such a relationship, whereas other research on anger has not. Anger often occurs amid a host of other possible influences, such as fear of punishment or self-control strivings that may interfere with anger directly resulting in aggression. Based on recent advances in the study of anger, we predict that anger associated with increased approach motivation and its corresponding neural activity should be related to increased behavioral aggression.

Anger is conceptually distinct from aggression (Parrott and Giancola, 2007). Moreover, anger does not always lead to aggression (Berkowitz, 1993). Self-reported anger correlates weakly with behavioral aggression in both laboratory (e.g. Kassinove *et al.*, 2002; Giumetti and Markey, 2007) and real-life situations (Nesbit *et al.*, 2007). The relationship between anger and behavioral aggression is likely to be influenced by several variables that have been largely unexplored in empirical research.

Anger is often, but not always (see Zinner *et al.*, 2008) associated with approach motivation (Harmon-Jones, 2003a; Carver and Harmon-Jones, 2009; Ford *et al.*, 2010). Anger with approach-motivated tendencies provides the urge to act outwardly and go toward the angering stimulus. From this perspective, anger is most likely to lead to aggression when anger is approach oriented. Indeed, Harmon-Jones and Peterson (2008) found tentative support for this idea when they found that angered individuals with high levels of chronic approach motivation who were primed with approach motivation expressed the most aggressive urges.

Other research has suggested that relatively greater left than right frontal cortical activation is associated with approach motivational processes (Amodio *et al.*, 2008; Schutter *et al.*, 2008; Berkman and Lieberman, 2010; Harmon-Jones *et al.*, 2010). Along these lines, research has suggested that anger associated with approach motivation evokes greater relative left frontal cortical activity (Harmon-Jones *et al.*, 2006; Peterson *et al.*, 2011). Anger that is not associated

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with approach motivation, because it is associated with low personal relevance or withdrawal-oriented motivation, does not evoke this pattern of cortical activation (Harmon-Jones *et al.*, 2006; Zinner *et al.*, 2008). Central to the aims of the current study, this anger-related relative left frontal cortical activation has been found to correlate with behavioral aggression (Harmon-Jones and Sigelman, 2001).

Instead of measuring cortical activation, research using brain stimulation has manipulated asymmetric frontal cortical activity to influence anger-related processes. For example, an impairment in processing of angry faces was observed after inhibition of the left prefrontal cortex as compared to inhibition of the right prefrontal cortex or sham stimulation (van Honk and Schutter, 2006; see also, d'Alfonso *et al.*, 2000).

The current study sought to extend past research by examining whether the manipulation of asymmetric frontal cortical activity during the experience of anger would influence actual aggressive behavior. We manipulated asymmetric activity by using the new and safe technique of transcranial direct current stimulation (tDCS; for a review, see Nitsche *et al.*, 2008). By means of weak electrical currents, bidirectional changes in cortical excitability can be induced, thought to result from subthreshold changes in the membrane potential (Nitsche and Paulus, 2000). Anodal tDCS leads to an increase in cortical excitability, whereas cathodal tDCS results in a decrease in cortical excitability (Nitsche and Paulus, 2000). tDCS has proved to be a well suitable technique to influence brain activity and investigate its behavioral and cognitive consequences (Wassermann and Grafman, 2005). Bilateral tDCS over the frontal cortex allows simultaneous manipulation of the left and right frontal cortex by increasing frontal activity in one hemisphere while decreasing activity in the corresponding contralateral hemisphere and thus allows for a means to study frontal asymmetry in relation to emotion and behavior (Fecteau *et al.*, 2007).

In the present study, we combined tDCS with a social psychological manipulation, interpersonal provocation, to investigate the role of anger and frontal asymmetry in aggression. Participants received tDCS that would cause greater left than right frontal brain activity (increase relative left frontal cortical activity condition), greater right than left frontal brain activity (increase relative right frontal cortical activity condition) or neither (sham condition). Following an interpersonal insult, participants were able to aggress by administering noise blasts to the insulting participant. We predicted a positive relation between self-reported anger to the insult and aggression after participants received tDCS to increase relative left frontal cortical activity. In other words, relative left frontal brain stimulation alone will not cause aggressive behavior. It will only cause greater aggression among those who are angered by the insulting feedback. Within the increase relative right frontal cortical activity and sham conditions, we expected a weak

relationship between anger and aggression, as in past research.

METHODS

Participants

Eighty healthy, right-handed introductory psychology students (40 females) participated in a double-blind sham-controlled counterbalanced between-subjects design in exchange for course credit. They had no psychiatric or neurological history and no contraindications for non-invasive brain stimulation (Keel *et al.*, 2000). None of the participants had damaged skin tissue, a skin disease (Nitsche *et al.*, 2008), were regular smokers or were on medications, except for women using oral contraceptives ($n = 13$). Data from 9 participants were unusable because of technical failures, and 11 participants' data were removed because of suspicion about the existence of the other participant. Participants were unaware of the aim of the study and naive to tDCS and written informed consent was obtained. The experiment was approved by the local ethics committee and was carried out in accordance with the standards set by the Declaration of Helsinki (Seoul Amendments).

Procedure

Participants were led to believe that they were participating in two separate experiments, one on impressions of personality and one on cognitive performance, as in past research (Harmon-Jones and Sigelman, 2001). In the first experiment, participants were told that the aim of the study was to investigate 'how people form impression of others based on writing and how personality is related to essay content and impressions'. Participants were also told they would receive brain stimulation for a short period to assess the 'relationship between personality and brain activity', whereas the second experiment was 'a reaction time game against another student'. The experimenter explained that the two experiments were performed in the same session because 'the experimenters wanted to collect as much data as possible'.

Upon arrival, participants completed a consent form, a questionnaire about contraindications and a self-report emotions scale that asked them to rate how they felt on words related to anger and other emotions (1 = very slightly/not at all to 5 = extremely; see Harmon-Jones *et al.*, 2009). Baseline anger was low ($M = 1.12$, $SD = 0.22$) and did not differ between conditions, $P = 0.48$.

Next, participants played three practice trials of the reaction time game, which familiarized participants with the game and reduced time between the insult and the aggression measure later in the experiment. Participants did not play against the other participant, and did not win or lose any trials.

Participants were told that they were randomly assigned to write an essay and that the other participant would evaluate their essay. They were able to choose between five controversial issues (e.g., public health care, war in Iraq) and were

asked to write a persuasive essay on their topic of choice they believed most strongly. After 10 min, the experimenter collected the essay and took it to the 'other participant' next door for evaluation.

After writing the essay, tDCS electrodes were attached and participants received tDCS for 15 min. During stimulation, the experimenter went next door to collect the feedback on the essay. After the stimulation, participants were given written feedback from the other participant (Harmon-Jones and Sigelman, 2001; Harmon-Jones *et al.*, 2004; Harmon-Jones and Peterson, 2009); it rated the participant on six characteristics (e.g., intelligence, respectability) on 9-point scales where 1 was most negative and 9 was most positive. The ratings were negative, between 2 and 4. Additional comments, in (gender-matched) handwriting, were, 'I can't believe an educated person would think like this. I hope this person learns something while at A&M'.

After participants read the feedback, they were told that the first experiment was finished and the second experiment was starting. Participants completed the Taylor Aggression Paradigm and finally completed a second self-report emotions scale that asked them to report how they felt during the experiment. It was administered at this point because past research has suggested that administration prior to measurement of aggression can inhibit aggression (Berkowitz, 1993). Across conditions, anger increased from baseline, $M_{\text{post}} = 2.20$, $SD = 1.03$, $t(59) = 8.03$, $P < 0.001$, but as expected, there was a wide-range of changes in anger from baseline (change score range from -0.40 to 4). Brain stimulation condition produced no differences in anger ($P > 0.05$).

tDCS

A battery-driven Magstim Eldith DC-stimulator Plus (NeuroConn GmbH, Ilmenau, Germany) was used for stimulation. Electrodes were 5×7 cm conductive-rubber electrodes placed in wet sponges saturated with electrode gel and fixed to the scalp. A current intensity of 2 mA was used for 15 min of stimulation. This resulted in a maximum current density of 0.057 mA/cm^2 and a total charge of 0.0512 C/cm^2 . A bipolar montage was used and electrodes were positioned over left (F3) and right (F4) prefrontal regions (10–20 EEG system). Both experimenter and participants were blind to the tDCS parameters, which were controlled by a separate investigator. Participants were randomly assigned to one of three conditions: anodal to left and cathodal to right frontal cortex ($n = 21$); anodal to right and cathodal to left frontal cortex ($n = 20$); or sham ($n = 19$). During sham stimulation, all settings except the duration of real stimulation were identical to the other conditions. Participants in the sham condition also received stimulation for 15 min, however, after the initial 5 s ramp-up period, real stimulation lasted for 30 s followed by a ramp-down period of 5 s. This is a reliable method of sham stimulation that does not produce after-effects (Gandiga *et al.*, 2006). Stimulation was well tolerated and participants did not

report any expectations that were in line with the hypotheses on the effect of brain stimulation. There were no differences between groups when participants were asked to guess if they received active or sham stimulation, $P > 0.6$.

Taylor aggression paradigm

A modified version of the widely used, reliable and valid Taylor (1966) Aggression Paradigm was used (Anderson *et al.*, 1999). In this game, participants are led to believe that they are playing a competitive reaction time game against the participant who earlier gave them insulting feedback. Participants played 20 trials (4 blocks of 5 trials), in which they have to press either the left or right shift key to a green plus sign presented on the left or right of the screen. They could win or lose a point on every trial. Participants were told at the beginning of each trial that they were able to give their opponent a 60–100 dB noise blast (in steps of 10 dB) if they won a trial. However, when they lost, they would receive a noise blast from the other participant. After each trial, the participants received feedback on the outcome of the trial. If the participants won the trial, they were able to determine the noise blast duration by pressing the spacebar for up to 10 s. If they lost, they received 85 or 102 dB noise blasts for either 5 or 7 s. Every participant lost and won the same trials, regardless of actual performance.

Data analysis

An aggression score was computed by averaging noise blast duration and volume ($r = 0.76$, $P < 0.001$). A stepwise linear regression analysis (method: probability of F to enter < 0.05 ; criteria probability of F to remove > 0.1) was employed to investigate the relationship between anger and aggression for the three tDCS conditions. Anger difference scores (post-provocation – baseline) were entered in the analysis. To test our interactive prediction, stimulation condition was entered as a dummy variable and the tDCS to increase relative left frontal cortical activity condition was always set to 0 because it was the critical condition against which the other conditions were compared. The following codes were used: (i) dummy variable 1: sham = 1; tDCS to increase relative right frontal cortical activity = 0; increase relative left frontal cortical activity = 0; (ii) dummy variable 2: sham = 0; increase relative right frontal cortical activity = 1; increase relative left frontal cortical activity = 0. The equation for the regression model is: aggression = b_0 intercept + b_1 anger + b_2 dummy₁ + b_3 dummy₂ + b_4 anger \times dummy₁ + b_5 anger \times dummy₂ (West *et al.*, 1996). Because the increase relative left frontal condition was set to 0 in both dummy variables, the equation for this condition is reduced to aggression = b_0 intercept + b_1 anger. The regression coefficient b_1 anger in the full equation gives the regression of aggression on anger in the increase relative left frontal cortical activity condition.

Furthermore, the dummy variables and the dummy \times anger variables assess the difference in mean aggression and the

Table 1 Results for stepwise linear regression analysis

	<i>b</i>	<i>P</i> -value
Overall model: $F(3, 56) = 6.47$, $P = 0.001$ $R^2 = .26$, $f = 0.35$		
Included predictors		
Regression of aggression on anger in the increase relative left frontal cortical activity condition.	1.27	<0.001
Difference in relation between anger and aggression for increase left frontal cortical activity vs sham condition.	-1.77	0.001
Difference in relation between anger and aggression for increase left frontal cortical activity vs increase right frontal cortical activity condition.	-1.01	0.04
Excluded predictors		
Difference in aggression for increase left frontal cortical activity vs increase right frontal cortical activity condition.	0.005	0.99
Difference in aggression for increase left frontal cortical activity vs sham condition.	0.14	0.74

b = unstandardized coefficient.

influence of anger on aggression for sham vs increase relative left frontal cortical activity condition (dummy 1 and dummy 1 × anger), and increase relative right vs left frontal cortical activity condition (dummy 2 and dummy 2 × anger). Anger difference scores (anger following insult minus baseline anger) were centered, and interactions were calculated as the product of anger scores and the dummy variables (West *et al.*, 1996). Cohen's effect size (*f*) was calculated using the following formula: $f = R^2/(1-R^2)$.

RESULTS

As predicted, individuals who received tDCS to increase relative left frontal cortical activity expressed more behavioral aggression when they scored higher on insult-related anger ($r(21) = 0.68$, $P = 0.001$). In contrast, participants who received either brain stimulation to increase relative right frontal cortical activity ($r(20) = 0.17$, $P = 0.47$) or sham stimulation ($r(19) = -0.34$, $P = 0.15$) did not become more aggressive when angry.

The overall regression model was significant, $F(3, 56) = 6.47$, $P = 0.001$ $R^2 = 0.26$, $f = 0.35$. Anger was a significant predictor for aggression in the increase relative left frontal cortical activity condition, $b = 1.27$, $P < 0.001$. In addition, significant dummy-coded interactions revealed that this relation between anger and aggression in the increase relative left frontal cortical activity condition differed from both increase right frontal cortical stimulation, $b = -1.01$, $P = 0.04$, and sham stimulation conditions, $b = -1.77$, $P = 0.001$. No other effects were significant (P 's ≥ 0.74 , see Table 1). Figure 1 shows the relations between anger and aggression for the three conditions.

DISCUSSION

After receiving tDCS to increase relative left frontal cortical activity, individuals expressed more behavioral aggression when they were angry. These results show the feasibility of combining brain stimulation with social psychological manipulations and measurements. While previous studies successfully incorporated tDCS with measurements of emotion and social behavior (Fecteau *et al.*, 2007; Knoch *et al.*, 2008), the present study is to our knowledge the first study to

combine tDCS and a social psychological manipulation. In addition to demonstrating the effectiveness of tDCS as a tool in the study of the neural mechanisms of social behavior, the present findings increase our understanding of the relationship between anger and behavioral aggression, by providing direct evidence that anger is more likely to relate to aggression when there is greater relative left frontal cortical activity.

The present results are consistent with the motivational direction model of frontal asymmetry in which relative left frontal cortical activity is associated with approach motivation (Harmon-Jones, 2003b), but they extend them in an important way by showing that the manipulated increase in relative left frontal cortical activity causes anger to be correlated with behavioral aggression and not just simply increase anger or aggression. In the last decade studies have showed that anger can be accompanied by approach motivation (for a review, see Harmon-Jones, 2003a; Carver and Harmon-Jones, 2009). A recent study showed that an aggressive personality style and selective attention for angry faces could be explained by an asymmetry in functional connectivity between the left and right cortices (Hofman and Schutter, 2009), suggesting that it is the functional relationship between left and right frontal cortical activity that likely influences angry-aggressive processes. This interpretation fits with other research that suggests that the right frontal cortical region is involved in behavioral inhibition (Cohen *et al.*, 2010). As the present study suggests angry-aggressive processes are likely the result of an increase in left frontal cortical activity (involved in approach) coupled with a decrease in right frontal cortical activity (involved in inhibition). When such psychophysiological processes occur, anger is more likely to lead to aggression.

While studies on the motor system and animal studies provide more insight into the mechanisms of tDCS (Nitsche *et al.*, 2008), the exact effect of stimulation on asymmetrical frontal cortical activity is unknown and warrants further research. In addition, future studies should pin point the precise effects of bilateral tDCS on approach and withdrawal-like behavior by incorporating different measurements of motivational tendencies. However, the present study shows the importance of combining basic

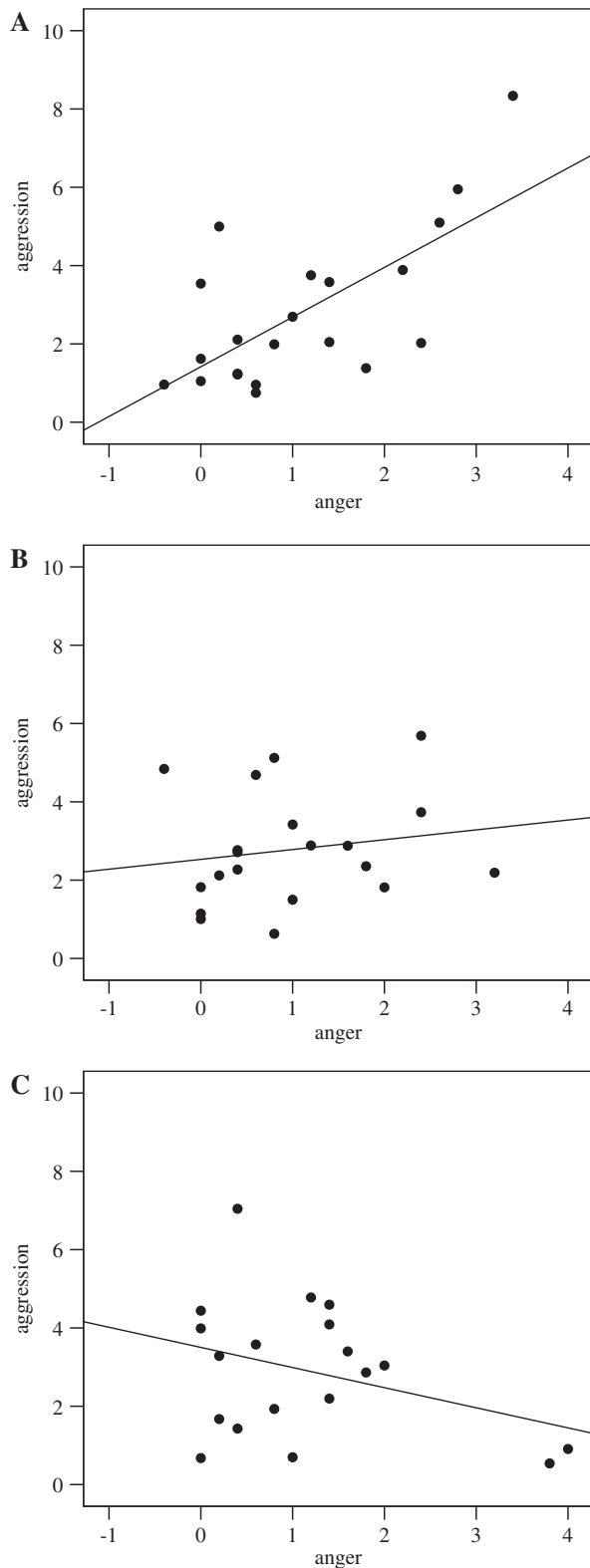


Fig. 1 The influence of anger on aggression in each condition. Anger was only related to aggression after participants received tDCS to (A) increase relative left prefrontal cortical activity, and not after tDCS to (B) increase relative right prefrontal cortical activity or (C) sham stimulation.

neurophysiological and social–psychological manipulations in investigations of human behavior. Non-invasive brain stimulation provides a novel way of manipulating human psychological processes in a direct way, and it allows a more precise investigation of specific mechanisms underlying social and affective behavior. In the present study, it provided a direct testing of theoretical considerations regarding anger and the link with aggression. The merger of social psychology and neuroscience has shown potential over the past 20 years, but the combination of non-invasive brain stimulation and social psychology will provide the field of social and affective neuroscience new ways of exploring the neural underpinnings of social behavior.

By successfully combining interpersonal provocation and non-invasive brain stimulation, the present study provides direct evidence for the relation between relative left frontal cortical activity, approach motivational tendencies and anger in aggressive behavior. Ultimately, research of this sort may lead to a better understanding of the neurobiological factors that cause aggressive acts.

Conflict of Interest

None declared.

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