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BRIEF REPORT

Jealousy Increased by Induced Relative Left Frontal Cortical Activity

Nicholas J. Kelley
Texas A&M University

Paul W. Eastwick
University of Texas at Austin

Eddie Harmon-Jones
The University of New South Wales

Brandon J. Schmeichel
Texas A&M University

Asymmetric frontal cortical activity may be one key to the process linking social exclusion to jealous feelings. The current research examined the causal role of asymmetric frontal brain activity in modulating jealousy in response to social exclusion. Transcranial direct-current stimulation (tDCS) over the frontal cortex to manipulate asymmetric frontal cortical activity was combined with a modified version of the Cyberball paradigm designed to induce jealousy. After receiving 15 min of tDCS, participants were excluded by a desired partner and reported how jealous they felt. Among individuals who were excluded, tDCS to increase relative left frontal cortical activity caused greater levels of self-reported jealousy compared to tDCS to increase relative right frontal cortical activity or sham stimulation. Limitations concerning the specificity of this effect and implications for the role of the asymmetric prefrontal cortical activity in motivated behaviors are discussed.

Keywords: jealousy, asymmetrical frontal cortical activity, transcranial DC stimulation, approach motivation, social exclusion, ostracism

Humans have a fundamental need to form and maintain interpersonal relationships (Baumeister & Leary, 1995). Circumstances that threaten to thwart the need to belong (e.g., social exclusion) can elicit a variety of negative reactions, from a loss of meaning in life (e.g., Stillman et al., 2009) and depression (e.g., Allen & Badcock, 2003) to physical aggression (e.g., Twenge, Baumeister, Tice, & Stucke, 2001). Another common response to circumstances that threaten relationship needs is jealousy (Leary, 1990). Jealousy refers to an emotional response to a real or perceived relationship threat. Unlike some other relationship threats, jealousy requires the presence of a triad in which one member of the triad perceives that a third person represents a real or imagined threat to a desired or current relationship (Parrott & Smith, 1993; Salovey & Rothman, 1991; White & Mullen, 1989). Jealousy has several implications for individuals, relationships, and society in general. For example, jealousy has been associated with dissatisfaction in close relationships (Andersen, Eloy, Guerrero, & Spitzberg, 1995) and intimate partner violence (Finkel, 2007). The current research examined neural mechanisms that modulate jealousy in response to social exclusion.

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Nicholas J. Kelley, Department of Psychology, Texas A&M University; Paul W. Eastwick, Department of Human Development and Family Sciences, University of Texas at Austin; Eddie Harmon-Jones, School of Psychology, The University of New South Wales; Brandon J. Schmeichel, Department of Psychology, Texas A&M University.

Correspondence concerning this article should be addressed to Nicholas J. Kelley, Department of Psychology, TX A&M University, 4235 TAMU, College Station, TX 77843-4235. E-mail: nicholasjkelley@gmail.com

Jealousy and Relative Left Frontal Cortical Activity

Jealousy has rarely been studied in the laboratory for both practical and ethical reasons, and most of the extant research has measured rather than manipulated jealousy (e.g., DeSteno & Salovey, 1996; DeSteno, Bartlett, Braverman, & Salovey, 2002; DeSteno, Valdesolo, & Bartlett, 2006). Recent research, however, has demonstrated the feasibility of experimentally manipulating jealousy. Harmon-Jones, Peterson, and Harris (2009) used a modified Cyberball paradigm to evoke jealousy. Under the guise of a mental visualization study, participants played a virtual ball-tossing game with two other (purported) participants. To make the visualization process easier, participants selected one partner from a series of eight photographs (participants were randomly assigned to choose among either male or female photographs), and the experimenter assigned a third partner of the same gender as the participant. In a first study using this paradigm, Harmon-Jones et al. found increased jealousy among excluded compared to included participants. Moreover, the magnitude of this difference was greater among participants who had been excluded by opposite-sex others compared to same-sex others. Exclusion by opposite-sex others did not influence feelings of inclusion, belonging, control, self-esteem, or meaningful existence compared to exclusion by same-sex others.[1] Moreover, the effect of exclusion by opposite-

[1] Harmon-Jones et al. (2009) observed a main effect of the Cyberball manipulation, such that excluded individuals reported lower feelings of inclusion, belonging, control, self-esteem, and meaningful existence relative to included participants. However, the Cyberball × sex of other interaction did not influence these outcomes.

sex others continued to influence jealousy even when controlling for these other subjective states. Thus, the manipulation used by Harmon-Jones and colleagues effectively induces jealousy.

A second study using the same paradigm found a positive correlation between jealousy and relative left frontal cortical activity, and neither jealousy nor relative left frontal cortical activity was associated with other responses to social exclusion (e.g., inclusion, self-esteem). Moreover, the relationship between jealousy and cortical asymmetry maintained significance when controlling for these other variables. Thus, not only did the experimental paradigm used by Harmon-Jones et al. (2009) increase jealousy, but relative left frontal asymmetry also predicted jealousy but not other self-report variables relevant to social exclusion. Although anger and self-esteem are often correlated with jealousy, results suggested that jealousy continued to predict relative left frontal activity when these variables were statistically controlled. A follow-up study by Peterson, Gravens, and Harmon-Jones (2011) yielded conceptually similar results.

Research with infants provided additional support for a link between asymmetrical frontal brain activation and jealousy. In a study by Mize and Jones (2012), infants were ignored by their mother in favor of a social rival (i.e., a lifelike doll) or a nonsocial rival stimulus (i.e., a book). Mize and Jones defined jealousy as a combination of approach-oriented behaviors, including eye gaze toward the mother or item, closer proximity to the mother, and touching of the mother or item, as well as increased negative affect and vocalizations of distress. They found more jealous behavior among infants ignored in favor of a social rival. Furthermore, in the social rival condition, jealousy related significantly to left frontal cortical asymmetry.

Relative left frontal cortical activity has been considered a neural correlate of approach motivation (Davidson, 1995; Fox, 1991; Harmon-Jones & Allen, 1997, 1998; Sutton & Davidson, 1997; see review by Harmon-Jones, Gable, & Peterson, 2010), so the results of Harmon-Jones et al. (2009); Peterson et al. (2011), and Mize and Jones (2012) suggest that approach-motivated brain activity is one possible neural mechanism linking social exclusion to jealous feelings. The present study builds on these findings by experimentally manipulating the presumed mechanism (i.e., relative left frontal cortical activity) using transcranial direct-current stimulation (tDCS) and testing for moderation of the relationship between social exclusion and jealousy (see Spencer, Zanna, & Fong, 2005).

tDCS and Asymmetric Frontal Cortical Activity

tDCS is a safe and noninvasive technique that influences cortical activity by means of a weak electrical current (for a review, see Nitsche et al., 2008). Anodal stimulation results in an increase in cortical excitability, whereas cathodal stimulation leads to a reduction in cortical excitability (Nitsche & Paulus, 2000). A recent study using tDCS by Hortensius, Schutter, and Harmon-Jones (2012) highlighted the feasibility of using tDCS to modulate socioemotional processes. They found that after receiving tDCS to increase relative left frontal cortical activity, individuals behaved more aggressively toward the purported insulter when they were angry. Stated another way, tDCS to increase relative left frontal cortical activity strengthened the relationship between anger and aggression. The findings of Hortensius et al. are consistent with motivational accounts of frontal brain asymmetry suggesting that greater left than right frontal brain asymmetry is associated with approach-motivated emotions, whereas greater right than left frontal brain activity is associated with avoidance-motivated emotions. In addition, these findings suggest that tDCS is well suited to study the influence of frontal asymmetry on emotional responding because it influences cortical excitability in a bidirectional fashion.

The Present Study

In summary, the goal of the current research was to extend the results of Harmon-Jones et al. (2009) by testing the causal link between relative left frontal cortical activity and jealousy evoked by social exclusion from a desired partner. Participants received tDCS to cause a manipulated increase in relative left frontal cortical activity, a manipulated increase in relative right frontal cortical activity, or sham stimulation. Then participants were either included or excluded during a Cyberball game. We made two predictions. First, we expected to replicate Harmon-Jones et al. (2009) by finding that excluded participants report greater feelings of jealousy compared to included participants. Second, we expected tDCS to modulate the effect of social exclusion on jealousy such that excluded participants who receive a manipulated increase in relative left frontal cortical activity report feeling more jealous relative to other excluded participants.

Method

Participants

In total, 117 right-handed undergraduate students (63 females) participated in a double-blind sham-controlled counterbalanced between-subjects design in exchange for credit toward a course requirement. 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 (except that women using oral contraceptives were included). Data from participants were excluded based on suspicions about the deception ($n = 14$; see below) or technical failure ($n = 11$). After these exclusions, data from 92 participants (52 female) remained for analysis. Participants gave written consent and were naïve to the aim of the study, tDCS, and Cyberball.

Power Analysis and Sample Size Selection

Sample size selection was based on a power analysis conducted with G-Power software (Faul, Erdfelder, Lang, & Buchner, 2007; Faul, Erdfelder, Buchner, & Lang, 2009). Based on an effect size coefficient from prior tDCS research ($\eta_p^2 = .11$; see Kelley, Hortensius, & Harmon-Jones, 2013), a sample of at least 82 participants was required to achieve an adequate amount of statistical power (.80; see Cohen, 1988, 1992). After exclusions, the current sample of 92 participants exceeded the target sample size.

Procedure and Materials

Participants were led to believe the experiment involved mental visualization and task performance (e.g., Zadro, Williams, & Richardson, 2004). After the consent process, participants learned they would be playing a virtual ball-tossing game in groups of three and that they would be randomly assigned to choose one of their partners or be chosen as a partner while a third partner was chosen randomly. To buttress the cover story, participants' photos were ostensibly taken to upload into the game (see Harmon-Jones et al., 2009). In reality, participants' photos were not taken, and they all got to choose one of their partners from a stock group of images of eight opposite-sex individuals. The third Cyberball player was assigned by the experimenter and was always the same sex as the participant. Next, participants played a practice version of Cyberball in which the two other players included the participant (i.e., the ball was thrown to them) consistently throughout the practice period (4 min). Participants pressed the left shift key to throw the virtual ball to the player on the left and the right shift key to throw to the player on the right. In addition to familiarizing participants with the Cyberball game, the practice game reinforced the norm of being included and thus helped to intensify the impact of any subsequent exclusion.

Next, participants received tDCS for 15 min following the same stimulation parameters as reported in Hortensius et al. (2012). A battery-driven Magstim Eldith DC-stimulator Plus (NeuroConn GmbH, 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/ramp-down: 5 s). A bipolar montage was used, and electrodes were placed in wet sponges saturated with electrode gel and fixed to the scalp positioned over left (F3) and right (F4) prefrontal regions (10–20 EEG system). On the basis of past EEG research that found that jealousy was positively correlated with relative left frontal cortical activity (Harmon-Jones et al., 2009), we placed electrodes at sites corresponding to those used in the past EEG research (i.e., over the dorsolateral prefrontal cortex, F3 and F4). Both experimenter and participants were blind to the tDCS parameters, which were controlled by a separate investigator.

Participants were randomly assigned, via a random-numbers table, to one of three conditions: increase in relative left frontal cortical activity (anodal over F3/cathodal over F4, $n = 28$), increase in relative right frontal cortical activity (cathodal over F3/anodal over F4, $n = 31$), or sham ($n = 33$). In the sham condition, all settings except the stimulation duration (ramp-up: 5 s; stimulation: 30 s; ramp-down: 5 s) were identical to the other conditions. This is a reliable method of sham stimulation that does not result in systematic aftereffects (Gandiga, Hummel, & Cohen, 2006). Participants in the sham condition waited the same duration of time between the practice version of the Cyberball game and the experimental Cyberball game. Participants were unable to correctly guess whether they received active or sham stimulation, $F < 1$, $p > .8$.

After 10 min of stimulation (with 5 min of stimulation remaining), participants played the Cyberball game again. All participants were included during the first 2 min of the game. Then, half of the participants were excluded during the second half of the game (i.e., the ball was not thrown to them). After tDCS and the Cyberball game, participants completed a postgame questionnaire to assess emotions and other reactions they had during the game (see Zadro et al., 2004).[2] Specifically, participants indicated to what extent they felt jealous during the Cyberball game using a 9-point scale from 1 = *not at all jealous* to 9 = *extremely jealous* (as in Harmon-Jones et al., 2009). Last, participants were asked the following: (a) "How did the experiment go?" (b) "Do you have any questions?" (c) "Did anything seem odd unusual or out of place?" and (d) "If you had to guess, what do you think the study was about?" Data from participants were excluded if they explicitly stated believing that the other participants were not real or knew that the experiment was about jealousy.[3]

Results

Jealousy

Our first hypothesis was that excluded participants would report greater feelings of jealousy than included participants. They did. A 2 (Cyberball: included vs. excluded) × 3 (tDCS: sham stimulation vs. increase in relative right frontal cortical activity vs. increase in relative left frontal cortical activity) between-subjects analysis of variance (ANOVA) on self-reported jealousy revealed a main effect of Cyberball, such that excluded participants ($M = 3.43$, $SD = 2.18$) reported feeling more jealous than included participants ($M = 1.40$, $SD = 1.01$), $F(1, 87) = 37.22$, $p < .001$. The main effect of tDCS was not significant, $F(2, 86) = 1.15$, $p = .33$.

Our second hypothesis was that the tDCS condition would modulate the effect of social exclusion on jealousy, with participants who received a manipulated increase in relative left frontal cortical activity paired with exclusion reporting the most jealousy. They did, as revealed by a planned comparison pitting this condition against all other conditions, $t = -5.10$, $p < .001$, Cohen's $d = 1.10$. In addition, a Cyberball × tDCS interaction was significant, $F(2, 86) = 3.36$, $p = .04$, $\eta_p^2 = .07$ (see Figure 1). Follow-up comparisons revealed two key findings. First, within each stimulation condition, social exclusion increased jealousy significantly relative to inclusion (sham condition, $p = .009$; increase in relative left frontal cortical activity condition, $p < .001$; increase in relative right frontal cortical activity tDCS condition, $p = .02$). Second, as predicted, among excluded participants, stimulation to increase relative left frontal cortical activity caused greater jealousy than either stimulation to increase relative right frontal cortical activity ($p = .01$) or sham stimulation ($p = .03$). Using Cohen's (1988) criteria, these comparisons revealed moderate to large effect sizes (Cohen's $d = 0.67$ and 0.72, respectively). Jealousy following social exclusion did not differ between the stimulation to increase relative right frontal cortical activity and sham stimulation conditions, $p = .74$.

[2] Due to a loss of data stemming from a computer malfunction, items on the postgame questionnaire other than the jealousy item were not available for analysis. Only responses to the jealousy item had been stored offline prior to the malfunction. That is, the first author had manually extracted the jealously values from the computer so that he could present these data in a laboratory meeting, and shortly thereafter the computer crashed.

[3] On an exploratory basis, we also measured aggressive behavior after the postgame questionnaire. Participants learned that the two partners they had played Cyberball with were participating in a second study that asked them to do a variety of yoga poses, and the participant was allowed to decide which yoga poses they should adopt. Aggression was operationalized as the total amount of time the participant assigned the romantic rival (i.e., the same-sex partner) and the romantic target (i.e., opposite-sex partner) to spend in four painful yoga poses. We observed no main effects of the exclusion manipulation, tDCS, or their interaction on aggression.

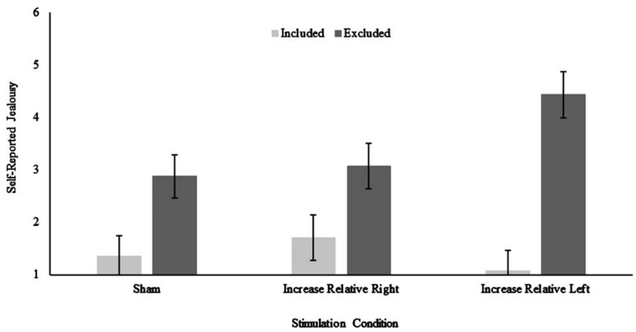

Figure 1. Among excluded participants, stimulation to increase relative left frontal cortical activity increased jealousy relative to stimulation to increase relative right frontal cortical activity or sham stimulation. Errors bars represent standard errors of the mean.

Discussion

Replicating previous research, the current experiment found that social exclusion in a modified Cyberball task induces the emotion of jealousy (see Harmon-Jones et al., 2009). More important, the present research found that a manipulated increase in relative left frontal cortical activity caused greater jealousy in response to social exclusion than did a manipulated increase in relative right frontal cortical activity or sham stimulation. No such effect occurred for included participants. These results support the view that induced relative left frontal cortical activity can increase jealousy in response to ostracism by a desired romantic partner.

The current findings suggest that the desire to approach underlies jealousy in response to exclusion from opposite-sex persons. This conclusion is supported by evidence that relative left frontal cortical asymmetry reflects approach motivation (e.g., Harmon-Jones & Allen, 1997, 1998), evidence correlating left frontal cortical asymmetry with jealousy (e.g., Harmon-Jones et al., 2009), and the current findings.

In past research, exclusion by desired opposite-sex partners has been found to increase jealousy but not increase other emotions (e.g., Harmon-Jones et al., 2009). In the past research, after participants were excluded by a same- or opposite-sex partner, they felt more anger and had lower feelings of inclusion, belonging, control, self-esteem, and meaningful existence. Whether the excluding partner was the same sex or opposite sex did not matter in influencing those feelings (i.e., there was simply a main effect of exclusion vs. inclusion). However, whether the excluding partner was the same sex or opposite sex did matter for influencing jealous feelings (i.e., there was an interaction of exclusion/inclusion and same/opposite sex of partner). Because the current research did not measure those other feelings, we cannot state with certainty that the tDCS manipulation would not influence these other nonjealousy affective reactions to exclusion by an opposite-sex partner. Therefore, future research should address this limitation by including these additional measures.

Jealousy and Approach Motivation

Why does increased activation of brain states associated with approach motivation increase jealousy? Jealousy is thought to have evolved in response to the problem of sexual or emotional infidelity (e.g., Buss, Larsen, Westen, & Semmelroth, 1992). Jealousy may activate approach motivation because the solutions to the adaptive problem of infidelity require approach-related action rather than inaction or avoidance. For example, to confront an unfaithful partner or a mate poacher, one must engage him or her in some capacity rather than avoiding that person or simply doing nothing. Consistent with this line of reasoning, approach motivation is implicit in many definitions of jealousy (e.g., Daly, Wilson, & Weghorst, 1982) and relates to the behavioral consequences of jealousy (e.g., aggression; Harmon-Jones & Sigelman, 2001). Thus, jealousy is likely modulated by an increase in approach-related brain activation because approach motivation could have increased the likelihood of success in dealing with cuckoldry in ancestral environments.

Underlying Mechanisms

The present effects may be rooted in cortical-subcortical interactions. One possible candidate is activity in a dorsolateral prefrontal cortex circuit. This circuit, which originates in the dorsolateral prefrontal cortex, projects to the thalamus through the basal ganglia and back to the dorsolateral prefrontal cortex (see Tekin & Cummings, 2002). Evidence from prior research pairing tDCS with functional magnetic resonance imaging found that stimulating the dorsolateral prefrontal cortex affects parts of the basal ganglia implicated in this circuit (e.g., the substantia nigra; Chib, Yun, Takahashi, & Shimojo, 2013). Chib and colleagues (2013) found that greater connectivity between the dorsolateral prefrontal cortex and basal ganglia regions (e.g., the substantia nigra, ventral tegmental area) predicted greater attractiveness ratings of computer-generated faces. It may be the case that activating this circuit activates the approach motivational system, which may explain why this circuitry was associated with attractiveness ratings in Chib and colleagues' study. Attraction, like jealousy, is approach motivated in nature, and thus, this circuit may also help to explain why stimulation to increase relative left frontal cortical activity increased feelings of jealousy in the current study. Future research pairing tDCS with imaging techniques should examine the extent to which greater activation of the prefrontal circuit predicts approach-motivated feelings and behaviors that are not necessarily rewarding (e.g., jealousy).

Another possible brain mechanism is the corpus callosum, which connects complementary regions in the cerebral hemispheres (e.g., the left and right prefrontal cortices) and is critical for interhemispheric communication. Recent research suggests that the corpus callosum may be a driving force underlying frontal cortical asymmetry and approach-motivated emotions and behaviors (Schutter & Harmon-Jones, 2013). For example, Hofman and Schutter (2009) used a callosal brain-stimulation paradigm and measured visual attention toward angry faces. They found that higher levels of interhemispheric signal transmission from the right to the left side of the brain correlated with increased attention toward angry faces in an emotional Stroop task. Based on this evidence, tDCS to increase relative left frontal cortical asymmetry may lead to jealousy through an increase in interhemispheric signal transmission toward the left side of the brain. Future work pairing tDCS with neuroimaging techniques should test this possibility.

The current study is the first to manipulate frontal brain activity and examine its effects on jealousy. The results represent a novel extension of past evidence of a correlation between relative left frontal cortical activity and self-reported jealousy after social exclusion (e.g., Harmon-Jones et al., 2009). By manipulating one presumed neural mechanism linking social exclusion to feelings of jealousy, the current study suggests that social exclusion leads to jealousy through an increase in relative left frontal cortical activity (Spencer et al., 2005). Along with other recent studies (e.g., Hortensius et al., 2012; Kelley et al., 2013), the results of the current research illustrate the value of using the neurostimulation technique of tDCS to advance understanding of processes of interest in social psychology and emotion science.

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