Uncertainty Modulates the Effect of Transcranial Stimulation over the Right Dorsolateral Prefrontal Cortex on Decision-making Under Threat

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Abstract

Threat is a strategy that can be used to impact decision-making processes in bargaining. Abundant evidence suggests that credible threat and incredible threat both influence the obeisance of others. However, it is not clear whether the decision-making processes under credible threat and incredible threat during bargaining involve differential neurocognitive mechanisms. Here, we employed cathodal transcranial direct current stimulation (tDCS) to deactivate the right dorsolateral prefrontal cortex (rDLPFC) to address this question while subjects allocated and reported the subjective probability of future rejection under incredible threat and credible threat. We found that application of cathodal tDCS over the rDLPFC decreased the proposer’s subjective inference of probability of rejection and the offer to the responder under incredible threat. Conversely, the same stimulation did not lead to a significant difference compared to the sham group in subjective probability and offer under credible threat. These results suggested that decision-making processes under the two types of threat during bargaining were associated with different neurocognitive substrates because the punishment for noncompliance was uncertain under incredible threat, whereas it was certain under credible threat. We decreased activity in the rDLPFC, which is involved in decision-making processes related to bargaining under incredible threats, and observed significantly impacted behavior. The differential neurocognitive bases of subjective probability of rejection under incredible threat and credible threat resulted in different tDCS effects.

Key words: incredible threat; credible threat; uncertain; decision-making; tDCS; rDLPFC;
1. Introduction

Bargaining is an essential part of social economic exchange. Many strategies, such as threats, are used by bargainers to impact others to derive more from the exchange. According to theories of classical economics, threat can be divided into incredible threat and credible threat. Credible threat means that the threatened person must satisfy the threatener’s desire because he/she knows that he/she will be punished if they do not comply. Conversely, incredible threat means that the threatened person does not need to satisfy the threatener’s demand because he/she does not believe they will be punished. Credible threat forces the threatened person to conform, whereas incredible threat does not (Klein and O'Flaherty, 1993; Kim, 1996). However, we feel that this view surrounding incredible threat is at odds with reality, in which the threatener sometimes claims incredible threats, and the threatened person does not always believe they will not be punished. Therefore, incredible threat is often used and demonstrated to be effective in influencing bargaining outcomes. Evidence supporting the usefulness of incredible threat derives from behavior experiments, in which several participants were more compliant under incredible threats (Straub et al., 1995; Croson et al., 2003).

Some studies explained the reason why incredible threat is effective (LeDoux, 2000; Dolan, 2002; Eimer and Holmes, 2002; Phelps, 2006, Witte, 1992). Based on the Fear Appeals theory, both incredible threat and credible threat evoke fear. Once fear is triggered in decision-making, it could alter the decision-maker’s expectations of the probability of future consequences and induce a more risk-averse choice if the consequences are uncertain (Lerner and Keltner, 2000, 2001; Loewenstein and Lerner, 2003). Since incredible threat might carry weight, the consequences of the threatened person’s actions are uncertain if he/she does not satisfy the threatener’s demand. In this condition, fear triggered by incredible threat evokes the threatened person to make more risk-averse choices and to increase his/her compliance. Unlike incredible threat, credible threat is believable because it narrows the threatener’s feasible set of actions or changes the threatened person’s payoff function to influence optimal choices (Selten, 1975). Moreover, the threatened individual perceives that punishment is certain to be administered when faced with credible threats if they do not meet the threatener’s request. Therefore, fear triggered by credible threats might not play a significant role. Thus, we proposed that the mechanisms of response to these two types of threat are different. However, little is known about whether responses to these two types of threat involve distinct psychological and neural mechanisms. Hence, this study aimed to use neuroscience techniques to explore these mechanisms.

Previous neuroscience literature focused on the neural correlates of threat-related responses. The amygdala plays an essential role in producing top-down signals on sensory pathways to influence representation of threat, and is responsible for rapid deployment of attention to threatening information (for reviews, see Bishop, 2007). Moreover, the amygdala is necessary for expression of conditioned fear (for reviews, see LeDoux, 2000). Acquisition and expression of conditioned fear can be prevented
through focal amygdala infusion to decrease amygdala activity (Muller et al., 1997). A series of attentional bias and anxiety studies using functional magnetic resonance imaging (fMRI) revealed common amygdala-prefrontal circuitry underlying the processes of conditioned fear and attention to threat (Bishop et al., 2004, Bishop, 2009, for reviews, see Ochsner et al., 2012). These studies suggested that the left dorsolateral prefrontal cortex (dLFP) plays a regulatory role in attentional deployment since reduced activity in the dLFP is associated with greater activity in the amygdala. In addition, studies using high-frequency repetitive Transcranial Magnetic Stimulation (HF-rTMS) and anodal transcranial Direct Current Stimulation (tDCS) techniques over the dLFP, which results in increased dLFP activity, revealed a casual role of the dLFP in modification of vigilance in response to threatening information (Raedt, 2010; Clarke, 2014; Heeren, 2016). In contrast, greater activation of the right DLPFC (rDLPFC) is associated with increased activation of the amygdala in response to fear (Paquette, 2003; Schienle, 2005). These findings support the concept that the rDLPFC maintains attention to threat via inhibition of attentional deployment to threat-irrelevant information or low-level threatening information (Eysenck, 2011; Peers, 2013; Sanchez, 2016). Two studies using bilateral-balanced tDCS over the dLFP and rDLPFC provided indirect evidence of the causal role of the rDLPFC in deployment of attention to threat (Ironside et al., 2016, 2017). In these studies, bilateral-balanced tDCS over the DLPFC (i.e., anodal tDCS over the dLFP and cathodal tDCS over the rDLPFC) significantly reduced amygdala activation and attention to threat in a dot probe detection task. However, bilateral-unbalanced tDCS over the dLFP did not have significant effects. These outcomes indicated that cathodal tDCS over the rDLPFC decreased amygdala activation and attention to threatening information.

In our study, we used a modified UG in which proposers made an allocation under credible threat and incredible threat to evaluate response to threat communication in bargaining. We aimed to distinguish the neural correlates associated with response to credible threat and incredible threat by stimulating the rDLPFC to modify attentional control of vigilance to threat. We predicted that incredible threat and credible threat both affect the distribution of allocation of the proposer in bargaining by changing beliefs regarding subjective probabilities of future rejection by the responder which would arise from altered offers. However, rDLPFC tDCS only modulated the effect of incredible threat on the proposer’s belief of the subjective probabilities of future rejection and allocation distribution, and played a minimal role when the proposer was faced with a credible threat.

2. Materials and Methods

2.1 Participants

Ninety-two healthy volunteers (48 females; between 18 and 28 years old) were recruited from all grades and campuses of Nankai University. All participants were right-handed with normal or corrected normal vision. The exclusion criteria were a
history of seizures or a history of neurological or psychiatric disorders. Every participant gave written informed consent before proceeding in the experiment. All experimental procedures were approved by the Ethics Committee of Business School of Nankai University. The study was carried out in accordance with the approved guidelines and the Declaration of Helsinki. Experimenters and participants were blind to the stimulation conditions. Participants were randomized into one of three stimulation groups: anodal (n = 31, 16 females), cathodal (n = 31, 16 females), or sham (n = 30, 16 females) stimulation of the rDLPFC. Two subjects, including a man in the cathodal stimulation group and a woman in the anodal stimulation group, reported discomfort during stimulation and were excluded from further analysis. Overall, information from 90 subjects was retained for data analysis (Table 1).

### TABLE 1 | Demographic characteristics of the three groups

| Items                | Cathodal tDCS (n=30) | Sham tDCS (n=30) | Anodal tDCS (n=30) | F     | p     |
|----------------------|----------------------|------------------|--------------------|-------|-------|
| Gender               | 0.533(0.093)         | 0.533(0.093)     | 0.500(0.093)       | 0.043 | 0.958 |
| Age                  | 22.800(0.497)        | 22.767(0.361)    | 22.767(0.380)      | 0.002 | 0.998 |
| Education            | 1.533(0.093)         | 1.533(0.093)     | 1.600(0.091)       | 0.175 | 0.840 |
| Career experience    | 0.400(0.149)         | 0.167(0.097)     | 0.167(0.084)       | 1.413 | 0.249 |
| Major                | 0.600(0.091)         | 0.567(0.092)     | 0.633(0.089)       | 0.135 | 0.874 |
| GPA                  | 2.333(0.121)         | 2.267(0.126)     | 2.367(0.148)       | 0.149 | 0.860 |
| Political conviction | 0.367(0.089)         | 0.367(0.089)     | 0.433(0.092)       | 0.182 | 0.834 |
| Household income     | 2.133(0.133)         | 2.133(0.133)     | 2.433(0.164)       | 1.442 | 0.242 |

Gender: 1 = female, 0 = male; Education: 1 = undergraduate, 2 = postgraduate; Career experience: working years; Major: 1 = economic, 0 = others; GPA: 1 = lower 50%, 2 = 20%-50%, 3 = the top 20%; Political conviction: 1 = Communist party members, 0 = others; Household income: 1 = less than 5000 CNY per month, 2 = 5000-10000 CNY per month, 3 = more than 10000 CNY per month.

All experimental procedures were conducted in the computerized group room of the Reinhard Selten Laboratory of Nankai University (Sellab). To conduct anonymous and fully randomized experiments, the group room was segmented into several cubicles with identical computer workstations, which were interconnected and shielded from each other.

### 2.2 Task

The experiment was a revised ultimatum bargaining game (Figure 1), and the main unit of analysis was defined as a “round”. In the experiment, the proposer would receive a threat message from his/her matched responder in each round, making claims about the responder’s future action. Then, he or she made an offer to the responder on how to divide 50G$ (game dollar, 1G$ = 1 yuan); the responder could either accept (i.e., the money was divided as suggested) or reject (i.e., both proposer and responder get no money) the offer. Each round did not offer feedback about acceptance or rejection. All
participants were required to play as proposers in this modified UG, and they were told that their responder would re-match after completion of a round. The participants had no information about their matched responders, and each pair interacted only through computers.

Fig. 1 (A) Structure of the modified UG. UG rules: The participant made an offer to the responder after he/she received a message from the responder. They were told if the responder accepted, and the money was divided as the proposer decided. If the responder rejected, they both received zero. The message had two types of information representing two types of threat, incredible threat and credible threat (INCT and CT). With each type of threat, the requested amount included a fair request and an unfair request (fair threat and unfair threat, short for FT and UNFT). ‘FT’ was a 25G$ request amount, ‘UNFT’ was a 35G$ request amount. The penalty represented a deduction if the responder accepted an offer lower than his/her request amount. (B) The tDCS placement is shown, representing the different stimuli conditions: cathodal stimuli, cathodal electrode over the F4 site, and extra-encephalic reference on the right shoulder; anodal stimuli, anodal electrode over the F4 site, and extra-encephalic reference on the right shoulder.

The experiment consisted of two parts. In the main paired portion (the second portion), each participant responded to 8 UG threats, including 4 incredible threats (INCT) and
4 credible threats (CT), with counter-balanced sequences. They were told that while their responders had to pay a penalty (the same as their request amount) for accepting an offer lower than their requested amount in CT, there was no penalty in the INCT condition. Therefore, they knew that if their offer did not meet the demands of the responder, they might not be rejected in the INCT condition, whereas in the CT condition they must be rejected. For both INCT and CT, the demand amount varied between 25G$ (the fair threat) (2 rounds), and 35 G$ (the unfair threat) (2 rounds). To control for individual differences, a standard UG without communication was conducted in the first part of the experiment as a baseline treatment (2 rounds). One example of the rounds for each game was as follows: CT: ‘If you offer me less than 25G$ (35G$), I will reject your offer, otherwise I will deduct 25G$ (35G$)’; INCT: ‘If you offer me less than 25G$ (35G$), I will reject your offer, otherwise I will deduct 0G$’; Baseline: ‘No communication in this round’.

For each experimental round, participants were presented with the threat, and they were required to make an offer within 30 s. At the same time, participants were asked to indicate the subjective probability of rejection if the offer was 1G$ less than the demanded amount (on an 11-point Likert-scale anchored at -5 to 5, -5: surely accept, 5: surely reject) and the subjective probability of rejection if the offer was 15G$ (on an 11-point Likert-scale anchored at -5 to 5, -5: surely accept, 5: surely reject). The first question screened whether the participant identified the credible threat and the incredible threat, and the second question measured and recorded the subjective probability of rejection. Fifteen G$ was chosen on the basis of Joseph Henrich’s research on UG (Henrich, 2000). Participant indication in the first part was only in response to the second question, since the proposer could not communicate with the responder. We randomly selected one round to pay them in each part. The average payoff was 60 yuan ($9.46) (range: $6.31–$12.62, standard deviation: $1.05). The experiment was programmed in z-Tree (Fischbacher, 2007).

2.3 Procedure and Stimuli

We recruited participants from the official accounts (Academy.org) of WeChat, BBS of Nankai University, or via e-mail. After participants were screened, we provided detailed information regarding the nature of the study, particularly the tDCS methodology. However, none of the participants were aware of the type of stimulation they received. On the day of the experiment, participants were led to an individual computer workstation. They read instructions and answered practice questions to determine that they appropriately comprehended the game. Details about how the game was played could be repeated as necessary.

A constant current flow of 1 mA was generated by a battery-driven stimulator (DC-Stimulator, NeuroConn, Germany) through a pair of a saline-soaked sponge electrodes (5 cm × 7 cm; current density: 0.057 mA/cm²). This weak current modulates regional neural excitability by increasing or decreasing resting membrane potentials (Ruff et al.,
223 Based on the findings of Ironside et al. (2016), the ‘active’ cathodal electrode or
224 anodal electrode was placed over the rDLPFC, on area F4 of the international 10–20
225 nomenclature for EEG (Electroencephalography electrode positioning). The ‘reference’
226 electrode was fixed extra-cephalically on the left shoulder (Figure 1B). The extra-
227 cephalic reference was chosen according to Claudia Civai’s study (Civai et al., 2014)
228 to prevent interference effects from brain areas beneath the reference electrode. Elastic
229 bands fixed the electrodes on the head and arm, and the electrical current impedance
230 was reduced by soaking the sponge with saline repeatedly.

231 In the cathodal or anodal tDCS conditions, the current was constant for 20 min with a
232 15 s rise and fall time, and the task started after current had been applied for 5 min. In
233 the sham tDCS condition, the participant was only stimulated during the first and last
234 30 s (15 s fade-in phase, 15 s fade-out phase). If the participant reported discomfort due
235 to stimulation, we stopped the experiment and provided compensation of 20 Yuan
236 ($7.88) as gratitude for participation. Participants practiced for 3 rounds before
237 participating in the formal task. At the end of the experiment, participants completed
238 questionnaires about basic demographic information (e.g., age, gender, monthly income)
239 and a risk preference test (Holt and Laury, 2002) showing the effect of stimulation on
240 risk attitude. This method of risk preference estimation allowed comparison of risk
241 attitudes across a wide array of contexts and environments (Charness et al., 2013).

242 Moreover, it was important to specify that tDCS was not focal and that the effects of
243 the stimulation were diffuse and not clearly confined to the area identified. However,
244 the area under the electrode was assumed to be the area most affected by the stimulation.

245 3. Results

246 We used two mixed-design ANOVAs to test for main effects and interactions in the
247 INCT and CT conditions. The between-subject factors were stimulation (cathodal,
248 anodal, and sham) effects on the proposer’s offer and subjective probability of rejection,
249 while the within-subject factors were fairness of request amount (fair threat vs unfair
250 threat, abbreviated FT vs. UNFT) when facing threat in bargaining. Every player
251 received all experimental treatments, so two mixed-design ANOVAs were chosen to
252 compare the impact of the two types of threat on decision-making in bargaining
253 between three stimulation groups to account for how threat changed the proposer’s
254 allocation behavior. To control for differences in the offer and subjective probability of
255 future rejection across individuals, we computed the following serial subtraction term
256 for each of the rounds of our paradigm: offer from INCT/CT - offer from baseline
257 (offer_{INCT/CT} – offer_{baseline}), subjective probability of 15GS from INCT/CT - subjective
258 probability of 15G$ from baseline (SP_{15GS-INCT/CT} - SP_{15GS-baseline}), eliminating the
259 interference of personal heterogeneity (e.g., initial willingness distribution preferences
260 vary from person to person). This means that the comparison in the two mixed-design
261 ANOVA was based on first order difference data. Paired t-tests were used to analyze
262 significant differences within subjects in threat (non-threatening bargaining,
263 threatening bargaining) and credibility (credible threat, incredible threat). All tests were

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two-tailed, and the significance level was set at \( P < 0.05 \). All statistical analyses were performed in SPSS 22.0 (IBM Comp, Armonk, NY).

3.1 Effect of threat and tDCS on behavioral allocation

We analyzed participant offers in the sham group under INCT and CT conditions using paired t-tests. We found that participant offers were significantly higher in the INCT-UNFT condition [mean ± se, 21.700 ±1.089 G$] than in the baseline condition [mean ± se, 17.775 ± 0.954 G$, \( p < 0.001 \)] and the INCT-FT condition [mean ± se, 19.950 ±0.830 G$, \( p < 0.001 \)], and they were higher in the INCT-FT condition than in the baseline condition [\( p = 0.019 \)] (Figure 2A). Participant offers were also significantly higher in the CT-UNFT condition [mean ± se, 30.150 ±1.357 G$] than in the baseline condition [mean ± se, 17.775 ± 0.954 G$, \( p < 0.001 \)] and in the CT-FT condition [mean ± se, 24.0083 ±0.628 G$, \( p < 0.001 \)], and were higher in the CT-FT condition than in the baseline condition [\( p < 0.001 \)] (Figure 3A). Hence, the nature of the threat changed the proposer’s decision-making and behavior, and greater requested amounts yielded greater offers.

Furthermore, we used the first order difference method to calculate the INCT and CT offers minus the baseline offers, respectively, in each round (\( \text{offer}_{\text{INCT}} - \text{offer}_{\text{baseline}}; \) \( \text{offer}_{\text{CT}} - \text{offer}_{\text{baseline}} \)). Then, we analyzed these differences using two mixed-design ANOVAs between three groups of stimulation (cathodal, anodal, and sham) to assess the influence of tDCS on the effect of threat on behavioral allocation.

Under INCT, a significant main effect of stimulation was observed [\( F (2,177) = 8.110, p < 0.001 \), Partial \( \eta^2 = 0.084 \)], with a lower effect on offer in response to incredible threat for the cathodal stimulation group (mean ± se, -0.696 ± 0.592 G$) than for the sham (mean ± se, 3.050 ± 0.616 G$, \( p < 0.001 \)) and anodal stimulation groups (mean ± se, 4.675 ± 0.638 G$, \( p = 0.015 \)). The effect on offer in response to incredible threat for the anodal stimulation group was comparable to that of the sham group (\( p > 0.1 \)) (Figure 2B). Another significant main effect was fairness [\( F (1,177) = 18.593, p < 0.001 \), Partial \( \eta^2 = 0.095 \)]. The INCT-FT offer was lower (mean ± se, 0.550 ± 0.431 G$) than the INCT-UNFT offer (mean ± se, 2.381 ± 0.487 G$). However, no significant interaction between fairness and stimulation was found under INCT [\( F (1,177) = 0.495, P > 0.1 \), Partial \( \eta^2 = 0.006 \)]. Under CT, there was only a significant main effect for fairness [\( F (1,177) = 206.091, p < 0.001 \), Partial \( \eta^2 = 0.583 \)]. CT-FT (mean ± se, 5.380±0.471 G$) had a lower average offer than CT-UNFT (mean ± se, 12.500±0.711 G$). However, no significant main effect of stimulation [\( F (2,177) = 0.639, P > 0.1 \), Partial \( \eta^2 = 0.007 \)], cathodal = 7.908± 0.644 G$, sham = 9.304 ± 0.988 G$, anodal = 9.608 ± 0.746 G$] (Figure 3B) or interaction between fairness and stimulation were found under CT [\( F (2,177) = 0.495, P > 0.1 \), Partial \( \eta^2 = 0.006 \)].
Fig. 2 Behavioral allocation in the INCT condition. (A) Effects of incredible threat including the mean offer amount to the partner and the standard error (y-axis) for sham (baseline, black; UNFT, red; FT, blue). (B) Effects of tDCS and fairness condition on the offer including offer change and the standard error (y-axis) for cathodal (C-tDCS, blue), anodal (A-tDCS, blue), and sham (black) stimulations for each fairness level (x-axis: INCT-UNCT = offer under incredible unfair threat, INCT-FT = offer under incredible fair threat). The interaction between fairness and stimulation was not significant.

Fig. 3 Behavioral allocation in the CT condition. (A) Effects of credible threat including the mean offer to partner and the standard error (y-axis) for sham (baseline, black; UNFT, red; FT, blue). (B) Effects of tDCS and fairness condition on offer including offer change and the standard error (y-axis) for cathodal (C-tDCS, blue), anodal (A-tDCS, blue), and sham (black) stimulations for each fairness level (x-axis: CT-UNCT = offer under credible unfair threat, CT-FT = offer under credible fair threat). The interaction between fairness and stimulation was not significant.

3.2 Effect of threat and tDCS on SP$_{15G}$

SP$_{15G}$ was recorded using an 11-point Likert scale, and represented the speculative likelihood of future rejection when a partner saw the offer was 15G$. We compared the inferred probability in the INCT and CT conditions with the baseline probability using paired t-tests. We found that participants’ SP$_{15G}$ values were significantly higher in the
INCT-UNFT condition [mean ± se, 1.267 ± 0.344 G$\$] than in the baseline condition [mean ± se, -0.1833 ± 0.331 G$\$, p < 0.001] and in the INCT-FT condition [mean ± se, 0.7333 ± 0.345 G$\$, p = 0.011]. In addition, these values were higher in the INCT-FT condition than in the baseline condition [p = 0.011] (Figure 4A). Participants’ SP$_{15G}$ values were also significantly higher in the CT-UNFT condition [mean ± se, 4.917±0.043 G$\$] and in the CT-FT condition [mean ± se, 4.833 ± 0.093 G$\$] than in the baseline condition [mean ± se, -0.1833 ± 0.331 G$\$, p < 0.001]. The CT-UNFT condition was comparable to the CT-FT condition [P > 0.1] (Figure 5A). Hence, threat appearance increased the proposer’s subjective probability of rejection in decision-making.

We used a similar method for inferred probability analysis. First, we calculated SP$_{15G}$ of INCT and CT, minus SP$_{15G}$ of baseline in each round (SP$_{15G}$-INCT – SP$_{15G}$-baseline; SP$_{15G}$-CT – SP$_{15G}$-baseline). Second, we analyzed these first order difference data by two mixed-design ANOVAs between three groups of stimulation (cathodal, anode, and sham) to assess the influence of tDCS on the effect of threat on the proposer’s subjective probability of rejection in decision-making. These results were consistent with the behavioral data.

Under INCT, we found a significant main effect for stimulation [F (2,177) = 5.475, p = 0.005, Partial $\eta^2 = 0.058$] with a lower effect in the cathodal stimulation group (mean ± se, -0.217 ± 0.240 G$\$) than in the sham group (mean ± se, 1.175 ± 0.246 G$\$, p = 0.009) and the anodal stimulation group (mean ± se, 1.025 ± 0.251 G$\$, p = 0.024). The effect of threat on subjective probability for the anodal stimulation group was comparable to that of the sham group (p > 0.1) (Figure 4B). Another significant main effect for fairness [F (1,177) = 16.172, p < 0.001, Partial $\eta^2 = 0.084$] was also observed. The subjective probability in response to INCT-FT was lower (mean ± se, 0.389 ± 0.200 G$\$) compared to that (mean ± se, 0.933± 0.200 G$\$) of INCT-UNFT. No significant interaction between fairness and stimulation on subjective probability was found under INCT conditions [F (2,177) = 0.103, P > 0.1, Partial $\eta^2 = 0.001$]. Under CT conditions, there was no significant main effect for fairness [F (1,177) = 0.319, P > 0.1, Partial $\eta^2 = 0.002$, CT-FT: mean ± se, 5.000± 0.189 G$\$, CT-UNFT: mean ± se, 5.022± 0.187 G$\$]. Moreover, we did not find a significant main effect for stimulation [F (2,177) = 0.807, P > 0.1, Partial $\eta^2 = 0.009$, cathodal = 4.700 ± 0.245 G$\$, sham = 5.058 ± 0.241 G$\$, anodal = 5.275 ± 0.198 G$\$] (Figure 5B) or an interaction between fairness and stimulation on subjective probability under CT conditions [F (2,177) =0.976, P > 0.1, Partial $\eta^2 = 0.011$].

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Fig. 4 $SP_{15G\$}$ in the INCT condition. (A) Effects of incredible threat including the mean $SP_{15G\$}$ and the standard error (y-axis) for sham (baseline, black; UNFT, red; FT, blue). (B) Effects of tDCS and fairness on $SP_{15G\$}$ including the change in $SP_{15G\$}$ and the standard error (y-axis) for cathodal (C-tDCS, blue), anodal (A-tDCS, blue), and sham (black) stimulations at each fairness level (x-axis: INCT-UNFT = change in $SP_{15G\$}$ under incredible unfair threat, INCT-FT = change in $SP_{15G\$}$ under incredible fair threat). The interaction was not significant between fairness and stimulation.

Fig. 5 $SP_{15G\$}$ in the CT condition. (A) Effects on credible threat including the mean $SP_{15G\$}$ and the standard error (y-axis) for sham (baseline, black; UNFT, red; FT, blue). (B) Effects of tDCS and fairness condition on $SP_{15G\$}$ including the change in $SP_{15G\$}$ and the standard error (y-axis) for cathodal (C-tDCS, blue), anodal (A-tDCS, blue), and sham (black) stimulations at each fairness level (x-axis: CT-UNFT = change of $SP_{15G\$}$ under credible unfair threat, CT-FT = change of $SP_{15G\$}$ under credible fair threat). The interaction was not significant between fairness and stimulation.

3.3 Effect of threat on $SP_{(x-1)G\$}$

We analyzed participants’ $SP_{(x-1)G\$}$, the subjective probability of rejection in response to an offer of $(x-1)G\$ (24/34G\$)$, in the INCT and CT conditions using paired t-tests. We verified whether participants were able to distinguish between credible and incredible threats clearly and whether they believed the threats. The participants’ $SP_{(x-}$
1) G$ values were significantly higher in the CT-UNFT condition [mean ± se, 4.783 ± 0.712 G$] than in the INCT-UNFT condition [mean ± se, -2.717 ± 0.353 G$, p < 0.001] and were higher in the CT-FT [mean ± se, 4.817 ± 0.099 G$] condition than in the INCT-FT [mean ± se, -2.550 ± 0.375 G$, p < 0.001] condition (Figure 6A). Participants’ SP(x-1) G$ values were also significantly higher in the cathodal [CT-UNFT = 4.750 ± 0.070 G$, INCT-UNFT = -3.600 ± 0.216 G$, p < 0.001; CT-FT = 4.867 ± 0.065 G$, INCT-FT = -3.367 ± 0.264 G$, p < 0.001] and anodal groups [CT-UNFT = 4.800 ± 0.071 G$, INCT-UNFT = -3.600 ± 0.210 G$, p < 0.001; CT-FT = 4.817 ± 0.073 G$, INCT-FT = -3.367 ± 0.243 G$, p < 0.001]. These findings indicated that participants not only distinguished between the two types of threats but also believed credible threats of non-obeisance and no gains. However, they could not ensure gains without obeisance under incredible threat.

Fig. 6 SP(x-1) G$ values under two type of threats. These bar plots report the mean SP(x-1) G$ values offered to partners and the standard error (y-axis) under two type of threats (CT, blue; INCT, red) and for each fairness level in different stimuli (x-axis: sham-UNFT = SP(x-1) G$ under unfair threat in sham group, sham-FT = SP(x-1) G$ under fair threat in the sham group; A-tDCS-UNFT = SP(x-1) G$ under unfair threat in the anodal group; A-tDCS-FT = SP(x-1) G$ under fair threat in the anodal group; C-tDCS-UNFT = SP(x-1) G$ under unfair threat in the cathodal group; C-tDCS-FT = SP(x-1) G$ under fair threat in cathodal group).

3.4 Effect of tDCS on personal risk preference

Data from the risk preference test were analyzed by one-way ANOVA. We did not find a significant main effect of stimulation [F (2,177) = 1.696, p > 0.1]. Neither cathodal [mean ± se, 11.557 ± 0.641 G$, p>0.1] nor anodal [mean ± se, 12.867± 0.579 G$, p > 0.1] stimulation impacted risk attitude compared to sham [mean ± se, 11.467 ± 0.577 G$]. These results suggested that the proposer’s behavioral data were not influenced by personal risk preference.
4. Discussion

The main aim of this study was to distinguish the neural correlates of responses to credible threat and incredible threat in bargaining. We performed an experiment to explore the involvement of the rDLPFC in bargaining under incredible and credible threat using tDCS, a technique that allowed modulation of cortical activation. We confirmed our hypothesis that cathodal tDCS of the rDLPFC decreased both subjective probability of future rejections and offers under incredible threat but not under credible threat. Moreover, our results suggested that the differential neurocognitive basis of reforming the subjective probability under incredible threat and credible threat enabled the tDCS effects.

The effects of tDCS mainly showed that cathodal stimulation over the rDLPFC under incredible threat bargaining led to a prominent difference compared with the sham condition in distribution and speculative likelihood of rejection (SP_{1GS}). Offer amount and subjective probability were dramatically lower in the cathodal condition. Interestingly, cathodal stimulation under credible threat did not result in a significant discrepancy in the subjective likelihood of rejection and its distribution compared to the sham group. This result suggested that when we reduced vigilance to threat in the task through stimulation applied over the rDLPFC (cathodal stimulation group), the threatened person’s belief of subjective probability of future rejection decreased significantly under incredible threat. This stimulation did not significantly impact individuals’ beliefs under credible threat. Hence, the rDLPFC, which controls the response to threat-related affective information in decision-making, is only recruited under perceptive cognition and processing of subjective probability under incredible threats. The neurocognitive mechanisms of subjective probability under credible threat did not involve the rDLPFC.

Our behavioral results showed that both incredible threat and credible threat are significantly different from the baseline condition with regard to speculative likelihood of rejection (SP_{1GS}) and allocation in bargaining. The subjective probabilities and offer amount dramatically increased in both the credible and incredible threat conditions. Consistent with “Messages influence beliefs, beliefs influence motivation, and motivation affects behavior” (Charness and Dufwenberg, 2006), these results demonstrated that appearance of messages which included incredible threat or credible threat information negatively impacted inference about future rejection by increasing subjective probability of rejection. In response, the subject increased the offer to the threatener. Under incredible threat, credibility of threat (SP_{x-1GS}) varied across individuals, and mean uncertainty of punishment was not always fixed (INCT-UNFT: 0% chose 5 and 1.11% chose 4/5 in SP_{x-1GS}; INCT-FT: 0.56% chose 5 and 1.67% chose 4/5 in SP_{x-1GS}). The speculative likelihood of rejection and its mean also varied (INCT-UNFT: 5% chose 5 and 18.89% chose 4/5 in SP_{1GS}; INCT-FT: 5% chose 5 and 11.68% chose 4/5 in SP_{1GS}). This indicated that the threatened person was uncertain of future rejection from the threatener if their offer amount was less than the threatener’s request.
Under credible threat, the credibility of threat and the speculative likelihood of rejection were identical among most individuals (CT-UNFT: 83.89% chose 5 and 93.89% chose 4/5 in SPx-1GS; 93.33% chose 5 and 98.89% chose 4/5 in SP15GS; CT-FT: 92.22% chose 5 and 92.77% chose 4/5 in SPx-1GS; 94.44% chose 5 and 97.22% chose 4/5 in SP15GS). This indicated that the threatened person was certain of future rejection if their offer amount was less than the request. A very early common finding was that physiological responses to the impending electric shock were consistent with the anticipated possible shock but not with the objective probability, except when the objective probability was zero (e.g., Monat et al., 1972). This outcome indicated that individuals’ subjective probability may deviate from objective uncertainty, and personal behavior correlated more strongly with subjective cognitive perception than objective nature unless subjective probability was the same as the objective certain probability in terms of zero or one hundred. In incredible threat conditions, when uncertain of rejection when the offer was less than the responder’s request, the threatened person’s allocation behavior was impacted by the subjective probability of an offer being rejected. However, this subjective probability would be affected by immediate emotion in decision-making (Loewenstein and Lerner, 2003; Lin, C. H et al., 2016; Chiu, Y. C et al., 2018). Fear of rejection caused by the threatener’s incredible threat likely prevented the subject from thinking rationally (Schotter et al., 1994; Van and Vermunt, 2000; Fellner and Guth, 2003) since the probability of future rejection was uncertain. This specific immediate emotion triggers under- or over-scrutiny of information (e.g., Blesser et al., 1996), and individuals are more likely to make relatively pessimistic risk judgements followed by risk-averse choices (Lerner and Keltner, 2000, 2001). Fear alters quality and/or quantity of information processing by altering the decision-maker’s perceptions of positive and negative outcome probabilities (Loewenstein and Lerner, 2003). Since the threatened person over-estimates the probabilities of disadvantageous outcomes, he/she makes a greater offer under incredible threat (e.g., Schotter et al., 1993; Straub and Murnighan, 1995; Croson et al., 2003; Carpenter and Matthews, 2004). In the credible threat condition, being certain of rejection when the offer is lower than the threatener’s request caused the threatened person’s subjective probability of rejection to increase to 100%, resulting in a higher offer amount compared to baseline. Our results in the credible threat condition were consistent with previous studies evaluating prediction of future moves (Van, 1989; Matthew, 1989; Snyder and Diesing, 2015) and beliefs about actions in psychological games based on models with belief-dependent components (Geanakoplos et al., 1989). Credible threats should be believed (e.g., Smoke, 1987), and the threatened person should adjust their actions according to the credible threat. Therefore, fear is unable to influence decision-making to affect inference of subjective probability and allocation.

Unfair threats are significantly different from fair threats, resulting in greater offer amounts in both the credible and incredible threat conditions. Moreover, the subjective probability of rejection was higher in response to unfair threats than in response to fair threats in the incredible threat condition, whereas the subjective probability of rejection was comparable in response to unfair and fair threats in the credible threat condition.
These findings, consistent with Rankin (2003), indicated that as more value is required by the threat, the subjective probability of rejection increases. The threatened person offered more under unfair incredible threat than under fair incredible threat.

Our behavioral data in response to credibility of threat also showed significant differences between credible threat and incredible threat for within-subject factors, demonstrating that individuals were able to distinguish incredible threat and credible threat when they were threatened in bargaining and had complete information about the pie being divided (50G$) and threat being faced (the penalty amount). This behavioral finding was consistent with previous studies, although actual bargaining behavior and traditional economic models of bargaining behavior often disagree with respect to response to incredible threat (Croson et al., 2003; Carpenter, 2007). The former posits that incredible threat affects beliefs and outcomes in specific situations while the latter does not (Lewicki, 1994; Croson et al., 2003; Charness and Dufwenberg, 2006). However, it is clear that individuals can distinguish between incredible threat and credible threat when precise information is provided (Selten, 1975; Klein and O'Flaherty, 1993; Croson et al., 2003).

In previous fMRI and tDCS studies (Paquette, 2003; Schienle, 2005; Eysenck, 2011; Bishop, 2009; Ironside et al., 2016, 2017), decreased activation of the rDLPFC specifically reduced attentional control of threat-related fearful material and controlled response of the amygdala to threat-related fear. Frontal cortex cathodal stimulation of the rDLPFC reduced vigilance to threat, which reduced hyperactivity in the amygdala and threat responsivity, preventing acquisition and expression of threat-related fear. Hence, a possible explanation for our results in response to cathodal rDLPFC stimulation is that the threatened person became insensitive to threat-related fear during attentional control of threat, and this process significantly prevented acquisition and expression of fear.

In incredible threat conditions, the probability of rejection is uncertain, and fear may lead to overestimation of threat and likelihood of rejection (Bless et al., 1996; Lerner and Keltner, 2000, 2001). Thus, a threatened person’s subjective probability regarding future rejection by the threatener was significantly higher, and they increased their allocation. However, cathodal stimulation prevented the effect of threat-related fear on the subjective probability of the threatened person, and his/her subjective probability of future rejection by the threatener did not increase as observed in the sham group. These results suggested that individuals in this group did not experience fear-induced changes in response to threat. Specific to incredible threat in our study, if a threatened person had formulated a prediction about the probability of alternative offers, including 15G$, and all possible emotional consequences of decision outcomes, then they chose the final offer after maximizing the balance of negative emotions and positive emotions resulting from every alternative offer. When incredible threat triggered fear, the threatened person’s predictions of the probability of rejection were impacted negatively, and the anticipated subjective probability increased, and response to fear influenced them to
make a larger offer. If we successfully reduced attentional control for threat-related fearful material using stimulation, the negative influence of fear on subjective probability would be reduced. Therefore, the subjective probability and allocation of the threatened person in INCT conditions with cathodal stimulation were significantly different than those in the sham group. In credible threat conditions, the lack of difference in the subjective probability of rejection compared to that in the sham condition may have resulted from the proposer updating the subjective probability of rejection directly in response to threat information to reflect a belief that they would be rejected in 100% of cases if the offer was lower than the demands of the threatener. Regardless of whether the threatened person felt fear, credible threat influenced decision-making by instilling certain subjective probability of rejection if the offer did not comply with the threat. Fear no longer factored into subjective probability, and attentional control of fear by the rDLPFC no longer had an effect.

To control for other aspects of choice behavior that may be affected by stimulation, we measured the preference of risk, as described by Holt and Laury (2002), between subjects because the DLPFC is associated closely with response to risk (Bechara et al., 1996; Kühnen and Knutson, 2005; Rao et al., 2008). In light of our results, cathodal or anodal stimulation over the rDLPFC did not impact risk attitude (Fecteau et al., 2007a, b; Yaple et al., 2017). In addition, previous studies showed that the DLPFC correlates with belief of inference or mental states in relation to others (Goel and Dolan, 2004; Costa et al., 2008; Kato et al., 2009; Yoshida et al., 2010). We controlled for the stimulation effect on belief alteration, and our results for SP_{150S} amounts in CT were not significantly different between subjects. This indicated that the subjective probability and choice behavior of participants was not directly affected by stimulus over the rDLPFC, which agreed with Yoshida et al. (2010). Moreover, since previous experimental studies showed that fairness of threat influenced the threatened person’s actions, we manipulated the fairness of credible threat and incredible threat by evaluating fair and unfair threats in both credible and incredible threat conditions (Rankin, 2003). Our results demonstrated that fairness of threats did not impact the effect of tDCS. Attentional control of threat in the rDLPFC refers to attentional control of threat-related negative affection or threat-related processing (Ochsner et al., 2004; Kaplan et al., 2007; Amodio et al., 2008) and not the message of threat being ignored. Therefore, the subjective probability of rejection and the offer in CT were not significantly different between subjects.

Rhetoric and statement are important in threat bargaining games (Matthews, 1989), so our statement of threat message was in strict accordance with the standard of Fear Appeals (Eagly and Haiken, 1993; Witte, 1992). We ensured that fear could be evoked and was a dominant emotion in our experiment. Threat-related processing is largely based on fear-related processes (Thorpe and Salkovskis, 1998; McKay, 2002), resulting in enhanced cognitive processing and physiological arousal (LeDoux, 2000; Dolan, 2002; Eimer and Holmes, 2002; Phelps, 2006).
Threat may also evoke anger and disgust, but not fear. Disgust suppresses sensory perceptual and attentional processing of disgust information to minimize contact (McNally, 2002; Krusemark and Li, 2011). This outcome suggests that if the dominant emotion in our experiment was disgust, individuals would pay little attention to the threat information and divide the pie at baseline levels. Fear and anger also have different effects. People express pessimistic risk estimates and make risk-averse choices under fear conditions, whereas they express optimistic risk estimates and risk-seeking choices under anger conditions (Lerner and Keltner, 2001). Anger evokes a fight, and fear leads individuals to want the fear-inducing stimulus to go away (Skitka et al., 2006). If anger was the dominant emotion in our experiment, individuals would have offered less than the baseline levels.

In response to anodal stimulation over the rDLPFC, we did not observe significant differences in between-subject factors compared with the sham group. We also showed that significant behavioral change resulted from unilateral neuromodulation of the rDLPFC. This unilateral salience might reflect a ceiling effect of attention on threat, and is consistent with the attentional control task in which vigilance to threat was reduced (Ironside et al., 2016).

5. Conclusion

Few previous studies have investigated the neural correlates of credible threat and incredible threat in bargaining. Both are thought to contribute to obeisance during bargaining, but the core neural basis of changing individual subjective probability under incredible threat was different than that under credible threat. We showed that cathodal tDCS stimulation commonly used to control amygdala response to threat-related processes did not affect the subjective probability of future rejections and offers in credible threat bargaining. However, tDCS decreased subjective probability of future rejections and offers in incredible threat bargaining. These findings suggested that the effects of tDCS may result from different neurocognitive mechanisms under the two types of threats.

6. Author Contributions

C.Z., J.P. and J.L. designed the experiment, C.Z. and P.J. carried out the experiment, C.Z. and J.P. analyzed the data, C.Z. and J.P. wrote the paper.

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