Table 3. Participant and experimenter conjectures about group assignment and blinding indices

Intervention	tDCS	Sham	Do not know	Total	James' blinding index	Bang's blinding index	95% CI
Participant's guess, *n* (%)							
tDCS	26 (32.1)	3 (3.7)	10 (12.3)	39 (48.1)		0.59	0.42, 0.76
Sham	18 (22.2)	9 (11.1)	15 (18.5)	42 (51.9)		−0.21	−0.41, −0.02
Total	44 (54.3)	12 (14.8)	25 (30.9)	81 (100)	0.57		0.49, 0.65
Experimenter's guess, *n* (%)							
tDCS	12 (15.4)	0 (0)	25 (32.1)	37 (47.4)		0.32	0.20, 0.45
Sham	2 (2.6)	2 (2.6)	37 (47.4)	41 (52.6)		0	−0.08, 0.08
Total	14 (17.9)	2 (2.6)	62 (79.5)	78 (100)[a]	0.84		0.76, 0.91

[a]Due to missing data, three cases were omitted from calculations of the blinding indices.

Table 4. Relationships between outcome variables (aggressive intent, moral wrongfulness, behavioral aggression) and baseline characteristics of the sample, assessed using *t* tests for dichotomous demographic variables (upper section) and Pearson correlations for continuous baseline variables (lower section)

Characteristic	Aggressive intent	Moral wrongfulness	Behavioral aggression
Sex[a]	−2.10*	4.21***	0.11
Race[b]	−0.08	0.06	−0.52
Age	−0.07	−0.01	−0.02
Grade point average	0.13	0.02	0.15
Social adversity	−0.08	0.09	−0.05
Variety of offending	0.36**	−0.21	0.001
Aggression	0.42***	−0.07	0.08
Psychopathy	0.17	−0.30**	0.20
Lack of premeditation	−0.07	0.11	0.28*
Sensation-seeking	0.17	−0.06	0.19
Anxiety	−0.02	−0.07	0.22
Self-control	0.01	−0.07	0.22

[a]Sex was coded as 0 for female and 1 for male.

[b]Race was coded as 0 for Caucasian and 1 for non-Caucasian.

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Discussion

This study tested a new approach to reducing aggressive and violent behavior. Individuals who underwent bilateral anodal stimulation of the DLPFC using tDCS reported a lower likelihood of committing an aggressive physical and sexual assault 1 d after stimulation compared with a sham control group. The treatment–aggressive intent relationship was partly accounted for by enhanced perception that the aggressive acts were more morally wrong, resulting from prefrontal upregulation. Findings help to strengthen conclusions from neurological, neuroimaging, and neuropsychological research (Damasio et al., 1994; Damasio, 2000; Yang and Raine, 2009; Liljegren et al., 2015; Rogers and De Brito, 2016) by documenting experimentally the role of the prefrontal cortex on the likelihood of engaging in aggression and the perception of such acts as morally wrong.

Beyond examining experimentally the role of the prefrontal cortex on a behavioral symptom, the finding that moral judgment partly mediates the effect of tDCS on the likelihood of sexual assault contributes to our mechanistic understanding of the etiology of sexual violence. It also provides partial support for the neuro-moral theory of violent behavior, which postulates that violence is due in part to impairments in brain regions subserving moral cognition and emotion (Raine and Yang, 2006). The null mediation effect observed for physical assault suggests that moral judgment plays a greater role on intentions to commit sexual assault, which is consistent with empirical evidence that sexual offenses, such as rape, are rated as more morally wrong than physical violence (Akman et al., 1968; Hsu, 1973). This indicates that moral judgment is likely only one of several processes underlying the prefrontal–aggression relationship.

The difference in our results for behavioral intent and the behavioral measure of aggression warrant attention. Although participants in the tDCS group exhibited significantly lower levels of aggressive intent after the experimental session, they exhibited a nonsignificant increase ($d = 0.26$) in behavioral aggression. These null findings converge with the mixed findings on tDCS and behavioral aggression in the literature to date (Hortensius et al., 2012). Furthermore, a recent case study of two female patients receiving anodal tDCS over the left DLPFC and a cathode over the right DLPFC reported anger attacks after stimulation, although notably, in contrast to the present study, these subjects were diagnosed with major depressive disorder (Hung and Huang, 2017).

Given empirical evidence that changes in intentions precede behavioral change (Webb and Sheeran, 2006), our results indicating lower intent to engage in aggressive acts following anodal prefrontal stimulation suggest that tDCS may be an initial step toward the reduction of aggression. This implication must, however, be tempered with the mixed findings in the extant literature. While the treatment and control groups did not differ on the behavioral measure of aggression, this finding is consistent with the concept that a single session of tDCS may have a limited effect on behavioral change. The longer-lasting therapeutic effects of tDCS are suggested to be associated with repeated, rather than single, sessions of stimulation (Nitsche et al., 2008). Therefore, beyond intent to engage in aggression, future studies need to evaluate whether behavioral changes may be observed with more stimulation sessions.

Several caveats are in order. First, the trial findings are limited to an ostensibly healthy population. As the first study to test the effect of prefrontal cortical upregulation on aggressive intentions, the generalizability of the findings to other samples remains to be seen. A second limitation is that moral judgment and aggressive intent were measured concurrently. Thus, we were unable to confirm the temporal order of the mediator and outcome variable. However, empirical evidence that moral judgments shape behavior (Reynolds and Ceranic, 2007) supports the notion that the mediation model presented reflects the expected temporal effects. Third, this study measured aggressive inclinations 1 d after the intervention. Further research is needed to determine whether tDCS can produce longer-term reductions in aggressive intent, as well as any reduction in aggressive behavior. Fourth, we were not able in our design to include stimulation of a "control" brain region to help document specificity of findings to the DLPFC. Although it has been documented that the right DLPFC is involved in moral judgment (Tassy et al., 2012), this study did not consider any laterality effects. Fifth, although the findings demonstrate that anodal tDCS resulting in a current flow through the