Anodal tDCS targeting the right orbitofrontal cortex enhances facial expression recognition

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Abstract

The orbitofrontal cortex (OFC) has been implicated in the capacity to accurately recognise facial expressions. The aim of the current study was to determine if anodal transcranial direct current stimulation (tDCS) targeting the right OFC in healthy adults would enhance facial expression recognition, compared with a sham condition. Across two counterbalanced sessions of tDCS (i.e. anodal and sham), 20 undergraduate participants (18 female) completed a facial expression labelling task comprising angry, disgusted, fearful, happy, sad and neutral expressions, and a control (social judgement) task comprising the same expressions. Responses on the labelling task were scored for accuracy, median reaction time and overall efficiency (i.e. combined accuracy and reaction time). Anodal tDCS targeting the right OFC enhanced facial expression recognition, reflected in greater efficiency and speed of recognition across emotions, relative to the sham condition. In contrast, there was no effect of tDCS to responses on the control task. This is the first study to demonstrate that anodal tDCS targeting the right OFC boosts facial expression recognition. This finding provides a solid foundation for future research to examine the efficacy of this technique as a means to treat facial expression recognition deficits, particularly in individuals with OFC damage or dysfunction.

Key words: transcranial direct current stimulation (tDCS); orbitofrontal cortex; facial expression recognition; mild brain stimulation; emotion

Introduction

The capacity to recognise the facial expressions of others is critical for effective social communication and behavioural regulation (Blair, 2003). The devastating social consequences of disruption to this ability have been observed in individuals in a range of clinical populations, including schizophrenia (e.g. Kohler et al., 2003), psychopathy (e.g. Hastings et al., 2008), autism spectrum disorder (e.g. Law Smith et al., 2010) and acquired brain injury (e.g. Babbage et al., 2011). The orbitofrontal cortex (OFC), which occupies the ventral surface of the prefrontal cortex (i.e. Brodmann’s areas 10, 11 and 47 in humans), has been particularly implicated in facial expression recognition (Kringelbach and Rolls, 2004; Heberlein et al., 2008). Individuals with lesions incorporating the OFC demonstrate impaired facial expression recognition (e.g. Hornak et al., 1996; Willis et al., 2014), with deficits observed on both forced choice labelling and rating tasks across facial expressions (Heberlein et al., 2008; Zald and Andreotti, 2010). These facial expression recognition impairments are thought to occur independently of perceptual impairments in face recognition (Hornak et al., 1996; Rolls et al., 1999).

Despite the evidence implicating OFC damage in deficits in facial expression recognition, effective treatments to remediate these facial expression recognition impairments are scarce. One method that is showing considerable promise as a cognitive remediation technique is transcranial direct current stimulation (tDCS). tDCS is a non-invasive technique which involves stimulation of the cerebral cortex by means of a weak constant direct current (usually 1–2 mA) applied to the scalp surface via large electrodes. Anodal stimulation is thought to induce excitatory effects on targeted brain regions, whereas cathodal stimulation...
results in inhibitory effects (Nitsche et al., 2003). Respectively, these effects are thought to relate to a shift in membrane potential towards depolarisation and hyperpolarisation, resembling neuroplastic alterations of cortical function (Keener et al., 2011; Kuo and Nitsche, 2012). Although there have been some inconsistencies in the behavioural effects that are observed following anodal and cathodal stimulation (e.g. Karim et al., 2010), several studies have demonstrated that anodal stimulation can lead to enhanced cognitive functioning in humans (see Kuo and Nitsche, 2012). For example, anodal stimulation of the dorsolateral prefrontal cortex (DLPFC) has been found to improve healthy adults’ performance in several cognitive domains, including verbal skills, executive function and memory (Sparing et al., 2008; Dockery et al., 2009). Notably, use of tDCS over extended sessions or multiple days has been shown to have benefits that are long-lasting, illustrating the potential efficacy of tDCS as a treatment approach to remediate cognitive deficits (Nitsche et al., 2009).

Despite the evidence suggesting that anodal stimulation can enhance cognitive performance in healthy adults, no previous study has examined whether anodal tDCS targeting the OFC can enhance facial expression recognition. The aim of the current study was to determine if anodal tDCS targeting the right OFC would enhance recognition of angry, disgusted, fearful, happy, sad and neutral facial expressions in healthy adults, as assessed with a forced-choice labelling task. We targeted the right OFC by applying anodal stimulation at electrode location FP2 (according to the international 10–20 EEG system), which maps onto Brodmann’s area 10 of the OFC (Koessler et al., 2009). We targeted the right OFC in preference to the left OFC, as the right OFC has been more consistently implicated in facial expression recognition in lesion and neuroimaging studies (e.g. Nakamura et al., 1999; Gorno-Tempini et al., 2001; Adolphs, 2002). Accuracy, reaction time and efficiency (see Jacques and Rossion, 2007) were the dependent measures of interest. In order to determine the behavioural specificity of anodal tDCS targeting the right OFC, participants also completed a control social judgement task. We hypothesised that anodal stimulation targeting the right OFC would lead to increased accuracy, faster reaction times and greater efficiency recognising facial expressions, compared with performance during the sham condition.

Materials and Methods

Ethics statement

All participants provided written informed consent to participate in the study in accordance with the Declaration of Helsinki. This research was approved by the Australian Catholic University’s Human Research Ethics Committee (HREC).

Participants

Participants comprised 20 (18 female) undergraduate psychology students from the Australian Catholic University, Sydney. Participants received course credit in return for their participation. Ages ranged from 18 to 34 (M = 21.35; s.d. = 3.86). All participants were right handed, were fluent in English, had normal or corrected-to-normal visual acuity and no history of brain injury, substance use disorder, neurological or psychiatric illness.

Stimuli

The stimuli were photographs of 10 individuals (five male) each displaying an angry, disgusted, fearful, happy and sad facial expression, as well as a neutral pose, for a total of 60 images. The images were selected from the Karolinska Directed Emotional Faces (KDEF) database (Lundqvist et al., 1998). The faces (256 grey levels, 72 ppi) were scaled to be the same size, covering a visual angle of 5.7° × 8.3°, at a viewing distance of ~60 cm.

Tasks

Facial expression recognition task

Facial expression recognition was assessed using a forced-choice labelling task. The aforementioned images were presented in a randomised order, centred on a black screen. Participants were asked to label the expression depicted in each face as angry, disgusted, fearful, happy or sad by clicking the appropriate label from the six emotion labels displayed underneath each face. Each image and the label options remained on the screen until a response was made. An inter-trial interval of 500 ms preceded the onset of the next trial. On average, participants took ~5 min to complete the task.

Control task

Participants completed a social judgement task in which they were asked to imagine a situation when they were leaving their local library when they saw a person carrying a pile of books, trip and drop all the books. Participants were shown the images described earlier in a randomised order and were asked to click on a visual analogue scale presented underneath the faces and indicate the extent to which they agreed with the statement: ‘I would approach this person and offer them help’. The response scale ranged from ‘Strongly disagree’ to ‘Strongly agree’, and the response was converted to a score ranging from 0 to 100. The face, statement and visual analogue scale remained on the screen until a response was made. An inter-trial interval of 500 ms preceded the commencement of the next trial.

tDCS

Prior to participation, all potential participants were screened to ensure their suitability for tDCS administration. The anodal electrode was placed over the right OFC (equivalent to location FP2, according to the international 10–20 EEG system), with the cathodal electrode positioned over the left parietal cortex (equivalent to location P3). P3 was chosen as a reference position to maximise the distance between the anodal and cathodal electrode, a technique thought to decrease the current shunted through the scalp and increase the current density in depth (Rockstroh et al., 1989). In the anodal condition, a constant current flow of 2 mA was applied through wet sponge electrodes (4 × 6 cm) and continuous tDCS was delivered by a battery driven, constant current stimulator (TCT Research) for 20 min. The stimulation commenced after 30 s ramp-up time, and participants commenced the tasks after 10 mins of stimulation. For the sham condition, placement of the electrodes, current intensity and ramp-up time were identical to the anodal tDCS condition; however, the stimulation only lasted for the 30-s duration of ramp-up time. This procedure has been promoted as a reliable method of sham administration (Gandiga et al., 2006) as it mimics the skin sensation at the beginning of tDCS without producing any neural altering effects on the brain (Hummel et al., 2005). Participants were blind to condition (i.e. anodal or sham), but the administrator was not. The effectiveness of blinding was demonstrated in the current study, as participants were at chance (50%) in Session 1 and below chance (42%) in Session 2.
at indicating whether they believed they had been in the sham or active stimulation condition.

Procedure
Participants attended the lab for the two sessions (i.e. anodal and sham), which were completed at least 48 h apart, with session order randomly counterbalanced across participants. All participants provided informed consent prior to the commencement of their first tDCS session. In the first session, participants completed a computerised demographic questionnaire followed by the control task and then the facial expression recognition task. The control task was completed before the facial expression recognition task to minimise the effect of the labelling cues on performance on the social judgement task. The second session comprised only the control task and the facial expression recognition task. The task was administered on a Dell computer with a 23-inch monitor at a screen resolution of 1920 × 1080, using Superlab 5.0 (Cedrus Corp., San Pedro, CA).

Statistical analyses
For the facial expression labelling task we assessed median reaction time for correct trials, accuracy and efficiency. Efficiency was derived for each condition by taking the median reaction time (for correct and incorrect trials) and dividing it by the proportion of correct responses (see Kennett et al., 2001; Jacques and Rossion, 2007). This gives an inverse efficiency score reported in ms, with smaller scores indicating better facial expression recognition. The benefit of using efficiency as a dependent measure is that it factors in both reaction time and accuracy. For the control task, we assessed approach ratings and median reaction time.

A series of two-way repeated measures analysis of variances (ANOVAs) were performed on the aforementioned dependent measures with the factors of tDCS condition (anodal and sham) and emotion (angry, disgusted, fear, happy, neutral and sad). The Greenhouse–Geisser epsilon adjusted value has been reported in all instances where the sphericity assumption was violated. As the assumption of normality was not met, a log, transformation was performed. Analyses were performed on the transformed data, however, we report the raw descriptive statistics to aid interpretation.

Results
Facial expression recognition
Median reaction time
Median reaction times, averaged across participants, are displayed in Figure 1. A significant main effect of tDCS condition emerged, \( F(1, 19) = 4.47, P = 0.048, \eta^2_p = 0.19 \), reflecting faster recognition of facial expressions in the anodal condition (\( M = 1784.23, \text{SE} = 72.47 \)), compared with the sham condition (\( M = 1921.15, \text{SE} = 89.59 \)). The tDCS Condition × Emotion interaction was not significant, \( F(5, 95) = 0.69, P = 0.632, \eta^2_p = 0.04 \). A significant main effect of emotion emerged, \( F(5, 95) = 21.31, P < 0.001, \eta^2_p = 0.53 \). Paired samples t-tests (Bonferroni adjusted) exploring the emotion main effect revealed that happy faces were recognised faster than all other emotions, \( t(19) > 4.35, P < 0.005, d > 1.04 \). Neutral faces were also recognised faster than angry, fearful and sad faces, \( t(19) > 3.95, P < 0.017, d > 1.23 \). All other comparisons failed to reach significance, \( t(19) < 2.91, P > 0.135, d < 0.97 \).

Proportion correct
Mean proportion correct for each condition is displayed in Figure 2. The main effect of tDCS condition was non-significant, \( F(1, 19) = 0.84, P = 0.370, \eta^2_p = 0.04 \). The tDCS condition × Emotion interaction was also non-significant \( F(5, 95) = 0.77, P = 0.577, \eta^2_p = 0.04 \). Again, a significant main effect of emotion emerged, \( F(2.78, 52.96) = 6.53, P = 0.001, \eta^2_p = 0.26 \). Paired samples t-tests (Bonferroni adjusted) revealed that happy faces were recognised more accurately than disgusted and sad faces, \( t(19) > 3.84, P < 0.017, d > 1.21 \). Although disgusted faces were recognised less accurately than fearful and neutral faces, \( t(19) > 3.80, P < 0.018, d > 0.95 \). No other significant differences emerged, \( t(19) < 3.33, P > 0.052, d < 1.06 \).

Efficiency
Mean efficiency for each condition is presented in Figure 3. The analysis revealed a significant main effect of tDCS condition, \( F(1, 19) = 4.62, P = 0.045, \eta^2_p = 0.20 \), reflecting more efficient facial
expression recognition in the anodal condition (M = 2004.18, SE = 117.63), compared with the sham condition (M = 2139.45, SE = 106.42). There was no significant interaction of tDCS condition × Emotion, F(2, 85, 54.22) = 0.54, P = 0.647, \( \eta^2_p = 0.03 \). A significant main effect of emotion again emerged, F(3, 13, 59.55) = 19.44, P < 0.001, \( \eta^2_p = 0.51 \). Paired samples t-tests (Bonferroni adjusted) revealed more efficient recognition of happy faces compared with all other emotions, t(19) > 4.55, P < 0.003, d > 1.12. Neutral faces were also recognised more efficiently than angry, disgusted, fearful and sad faces, t(19) > 3.59, P < 0.029, d > 1.20. All other comparisons failed to reach significance, t(19) ≤ 0.54, P ≥ 0.500, d ≤ 0.17.

Control task

Approachability ratings
Mean approachability ratings for each condition are presented in Figure 4. The main effect of tDCS condition was not significant, F(1, 19) = 0.00, P = 0.964, \( \eta^2_p = 0.00 \), and there was no significant interaction of tDCS condition × Emotion, F(2, 59, 49.19) = 0.44, P = 0.696, \( \eta^2_p = 0.02 \). The main effect of emotion was significant, F(2, 39, 45.40) = 31.92, P < 0.001, \( \eta^2_p = 0.63 \). Paired samples t-tests (Bonferroni adjusted) revealed that happy faces were rated as more approachable than all other expressions, t(19) ≥ 4.65, P ≤ 0.003, d ≥ 1.27, while disgusted and angry faces were rated as less approachable than all other expressions, t(19) ≥ 4.77, P ≤ 0.002, d ≤ 0.74. There was no significant difference in ratings assigned to neutral faces compared with sad and fearful faces, t(19) ≤ 1.68, P ≥ 0.500, d ≤ 0.34, sad faces compared with fearful faces, t(19) = 2.71, P = 0.207, d = 0.35, or angry faces compared with disgusted faces, t(19) = 1.66, P > 0.500, d = 0.26.

Median reaction time
Median reaction times, averaged across participants, are displayed in Figure 5. The main effect of tDCS condition was not significant, F(1, 19) = 0.42, P = 0.526, \( \eta^2_p = 0.02 \), and there was no significant interaction of tDCS condition × Emotion, F(2, 91, 55.29) = 0.95, P = 0.422, \( \eta^2_p = 0.05 \). The main effect of emotion was significant, F(5, 95) = 5.55, P < 0.001, \( \eta^2_p = 0.23 \). Paired samples t-tests (Bonferroni adjusted) revealed that reaction times were faster when judging happy faces compared with angry, fearful and neutral faces, t(19) ≥ 4.03, P ≤ 0.011, d ≥ 0.73. All other comparisons failed to reach significance, t(19) ≤ 3.26, P ≥ 0.062, d ≤ 0.69.

Discussion
The aim of the current study was to determine if anodal tDCS targeting the right OFC enhanced facial expression recognition in healthy adults. As hypothesised, anodal tDCS did lead to enhanced facial expression recognition, when performance was compared with the sham condition. This was evident in median reaction time, as well as efficiency. Although accuracy of facial expression recognition showed a similar trend in the anticipated direction, the effect size was small, and it failed to reach statistical significance. Importantly, anodal tDCS did not result in changes in the nature and speed of responses on the control task, which involved the exact same facial expression stimuli, suggesting that the observed effect reflects an actual enhancement in facial expression labelling performance and not a generalised improvement in speed of behavioural responses to emotional faces.

The principal finding of this investigation was that anodal tDCS targeting the right OFC increased the efficiency and speed of facial expression recognition. Although the facilitatory effects of anodal stimulation on cognitive performance have not been demonstrated in every instance (e.g. Karim et al., 2010), the current findings are in line with the assumed function of anodal tDCS as a technique that can lead to increased excitability of
the stimulated neural tissue and in turn result in enhanced cognitive performance (Nitsche et al., 2008). In addition, this finding aligns with the outcomes of previous studies, which have reported improved performance in several cognitive domains following anodal application (Sparing et al., 2008; Dockery et al., 2009). The benefits of anodal stimulation have been demonstrated by other brain-behaviour pairs, such as improved reaction time, motor learning, and functional recovery after stroke following stimulation of the primary motor cortex (Nitsch et al., 2003; Antal et al., 2004; Khedr et al., 2013) and enhanced performance on cognitive tasks following application to the left DLPFC (Kincses et al., 2004; Fregni et al., 2005; Iyer et al., 2005) and bilateral intraparietal cortex (Klein et al., 2013). This study is the first to demonstrate a direct relationship between anodal tDCS targeting the right OFC and enhanced facial expression recognition and provides initial support for this technique as a means to enhance facial expression recognition in healthy adult populations.

Although the current study provides evidence to suggest anodal stimulation is effective in enhancing facial expression labelling speed and efficiency, the independent effect of accuracy was not significant. It is likely that this lack of effect may reflect the fact that a number of participants performed at ceiling in the sham condition providing no potential for anodal stimulation to improve accuracy. Moreover, the participants were young, healthy adults without a history of neurological disturbance. The relevance of task complexity to performance on facial expression recognition tasks was recently demonstrated by Willis et al. (2014) who found that patients with OFC damage demonstrated impaired labelling relative to healthy and brain damaged control groups, for negative facial expressions when stimuli were shown for a short length of time (500 ms), but not when these expressions were shown for longer periods (5000 ms). This is consistent with the argument of Graham et al. (2007) that long presentation durations of stimuli may mask difficulties in facial expression recognition by giving patients time to employ compensatory cognitive strategies. In line with this approach, our data demonstrated that anodal stimulation targeting the right OFC did not improve accuracy of recognition per se, but improved the efficiency and overall speed at which this recognition took place. Further replication of this task using restricted stimulus presentation durations that eradicate ceiling effects may be more likely to provide evidence of an enhancement in accuracy of facial expression recognition following anodal tDCS targeting the right OFC. In addition, our study had a predominance of female participants, due to recruitment from an undergraduate psychology pool, which had a disproportionate ratio of female students. It is unclear whether our findings are generalisable to males, particularly as there is some indication that an individual’s sex can influence the effect of tDCS targeting the OFC when making moral judgements (Fumagalli et al., 2010). Further investigation to determine if there are sex differences in the effect of tDCS on facial expression recognition will be required.

One valid question that may be raised pertains to the specificity of effects achieved through tDCS. Although the electrode placement was specifically chosen to target the OFC, it is unclear to what extent the stimulation was localised to this particular region. As tDCS utilises large electrodes, and the current passes throughout the brain, tDCS effects are likely to be more diffuse than the targeted brain region, such as involving a larger area of the right hemisphere (Fregni et al., 2005; Karim et al., 2010). In further studies, use of anodal tDCS in combination with functional magnetic resonance imaging (fMRI), would be highly beneficial to determine the brain changes that accompany the observed behavioural effect. fMRI has been used successfully in a number of studies to identify the structures relevant to facial expression processing (e.g. Gorno-Tempini et al., 2001), and combining fMRI and tDCS would allow greater insight into the neural networks that are activated, and most importantly, the distribution, direction and extent of tDCS-mediated effects on brain physiology (Luft et al., 2014). Application of computational models (e.g. models that predict brain current flow in a targeted region as a function of stimulator settings and combinations of electrode placements) may also help to refine study design, optimise stimulation effects, and provide insight into individual anatomical differences that influence current flow (see Bikson et al., 2012).

A further avenue of study would be to determine whether anodal stimulation to other cortical regions could achieve comparable results. For instance, the DLPFC is involved in processing of stimuli with emotional context (e.g. faces and visual scenes; see Ueda et al., 2003; Sergerie et al., 2005), and there is some suggestion that anodal tDCS to the left DLPFC may improve reaction times on emotion detection tasks in healthy adults (Nitsche et al., 2012). The specific importance of the OFC to facial expression recognition has been drawn out not only from studies of patients with lesions to this region (Hornak et al., 1996; Willis et al., 2014) but through observation of the extensive neural connections between the OFC and the amygdala, a structure automatically engaged when facial expressions are viewed (e.g. Emery and Amaral, 1999; Tomita et al., 1999; Adolphs, 2002). It is however possible that the application of anodal tDCS to other cortical areas may also result in beneficial effects on facial expression recognition. In addition, cathodal stimulation targeting the right OFC would help to establish whether the anticipated disruptive effects to facial expression recognition occur. This would help to delineate whether behavioural change due to tDCS application is specific to one stimulation polarity, or whether an effect can be observed in both application forms.

The findings of the current study are the first to demonstrate that anodal tDCS targeting the right OFC enhances facial expression recognition. An obvious avenue for future research to extend on this finding would be to examine the effect of anodal stimulation targeting the right OFC, in special populations with facial expression recognition difficulties that are thought to be attributed, at least in part, to damage or dysfunction in the OFC, such as those with OFC damage (e.g. Willis et al., 2014), as well as those schizophrenia (e.g. Brüne, 2005), psychopathy (e.g. Deely et al., 2006) and autism spectrum disorder (e.g. Pelphrey et al., 2002; Law Smith et al., 2010). Notably, in the current study, anodal tDCS was administered in a single session, and the enhancements that this brings to cognition are thought to be only short-term, of ~1-h (Nitsche et al., 2008). However, tDCS has been shown to provide longer lasting effects after repeated sessions. For instance, anodal tDCS sessions completed over five consecutive days resulted in significant improvement in motor skill acquisition when compared with those who had received the sham condition, and this enhanced functioning was still observed at a 3 month follow-up (Reis et al., 2009). Research into the stability of the beneficial effects of anodal stimulation targeting the OFC that we achieved in this current study would be useful to provide support for the potential efficacy of tDCS as a treatment approach for individuals with facial expression recognition difficulties.

In sum, the current study has demonstrated that anodal tDCS targeting the right OFC can enhance facial expression...
recognition. This finding is the first to demonstrate the utility of anodal tDCS targeting the right OFC as a means to enhance facial expression recognition and provides a solid foundation for further research to examine the potential efficacy of this technique as a means to treat facial expression recognition deficits. Anodal tDCS targeting the right OFC represents a promising neuromodulatory technique with the potential to not only enhance facial expression recognition, but also to expand our understanding of the neural mechanisms underlying impaired facial expression recognition.

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