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Null effect of anodal and cathodal transcranial direct current stimulation (tDCS) on own- and other-race face recognition

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Abstract

Successful face recognition is important for social interactions and public security. Although some preliminary evidence suggests that anodal and cathodal transcranial direct current stimulation (tDCS) might modulate own- and other-race face identification respectively, findings are largely inconsistent. Hence, we examined the effect of both anodal and cathodal tDCS on the recognition of own- and other-race faces. Ninety participants first completed own- and other-race Cambridge Face Memory Test (CFMT) as baseline measurements. Next, they received either anodal tDCS, cathodal tDCS or sham stimulation and finally they completed alternative versions of the own- and other-race CFMT. No difference in performance, in terms of accuracy and reaction time, for own- and other-race face recognition between anodal tDCS, cathodal tDCS and sham stimulation was found. Our findings cast doubt upon the efficacy of tDCS to modulate performance in face identification tasks.

Keywords: transcranial electrical stimulation, brain stimulation, face perception, face memory, tDCS

Introduction

Face recognition is important for many social interactions that occur in our everyday life (Jack & Schyns, 2015). Although face recognition is used extensively, research has shown that we are not experts in recognizing unfamiliar faces (Bruce et al., 1999; Davis & Valentine, 2009; Kemp et al., 1997; White et al., 2014; Young & Burton, 2018). For example, passport control officers present high error rates (14%) in face matching despite having years of experience and having received specific training in the task (White et al., 2014). Difficulties in face identification are even more prominent with other-race faces (Meissner & Brigham, 2001). The other-race effect (ORE) in face recognition shows that humans tend to be better at recognizing own-race faces compared to other-race faces (Estudillo et al., 2020; Malpass & Kravitz, 1969; Wong et al., 2021). The ORE has been found across different tasks and countries, and even when the morphological differences across the faces are minor (McKone et al., 2011), pointing to a very robust phenomenon.

Own and other race faces are recognized differently and potentially involve different neural mechanisms. Prior research has reported greater activation to own-race compared to other-race faces in different brain areas such as the occipital face area, the fusiform gyrus, the right inferior frontal gyrus, and the right medial frontal cortex (Feng et al., 2011; Golby et al., 2001; Kim et al., 2006). Interestingly, although the activation in the fusiform face area is initially stronger for own-race faces, the activation for other-race faces increases over time, eventually surpassing the response to own-race faces (Natu et al., 2011). This suggests that own-race faces are processed more automatically compared to other-race faces. Furthermore, event-related potential (ERP) research has generally found larger N170 amplitudes in response to other- compared to own- race faces (Anzures & Mildort, 2021; Giménez-Fernández et al., 2020; Yao & Zhao, 2019, but see Cassidy et al., 2014; Senholzi & Ito, 2013; Wiese, 2013, for a reversed pattern). This finding has been associated with a disruption of configural face processing (Jacques & Rossion, 2010), as it is comparable to the N170 face inversion effect, where larger N170 amplitudes are observed for inverted faces as opposed to upright faces (Eimer, 2000; Goffaux et al., 2003; Rossion et al., 1999).

Other ERP components, such as the P100 (Anzures & Mildort, 2021; Giménez-Fernández et al., 2020) and P200 (Anzures & Mildort, 2021; Wiese, 2013) have also shown differences between own- and other-race faces (for a review, see Serafini & Pesciarelli, 2022).

Improvement of face recognition for **own- and other-race faces** could be important for individuals with developmental and neurological disorders that are associated with face recognition deficits such as prosopagnosia (Rossion, 2014), autism (Weigelt et al., 2012) and schizophrenia (Marwick & Hall, 2008); but see (Bortolon et al., 2015). Prosopagnosia, also known as face blindness, is a visual impairment that affects face recognition despite intact visual acuity and intelligence (Bate & Tree, 2017). Individuals with prosopagnosia may face difficulties in recognizing unfamiliar faces (Duchaine et al., 2006), familiar faces (Busigny & Rossion, 2010) and occasionally their own face (Parketny et al., 2015). Failure in recognizing familiar identities (e.g., family members and friends) could contribute to negative consequences such as feeling of embarrassment and guilt which may build up anxiety, increase fear of social interaction and lower levels of self-confidence (Dalrymple, Fletcher, et al., 2014; Yardley et al., 2008). **Own- and other-race** face recognition improvements could also be important in terms of public security. In fact, errors in the identification of unfamiliar faces in public security could lead to serious personal and societal consequences such as wrongful conviction of an innocent person while the actual criminal remains unrestrained. Given the catastrophic consequences of inaccurate face recognition in terms of public security and for individuals with developmental and neurological disorders associated with face recognition deficits, it is important to develop effective ways of improving face recognition skills.

One possible method of improving face recognition is by using transcranial direct current stimulation (tDCS). TDCS is a form of non-invasive brain stimulation technique where a low-level intensity electrical current is delivered between two or more electrodes attached to the scalp to modulate neuronal excitability (Reed & Cohen Kadosh, 2018). **TDCS brings the neurons closer to their firing threshold without eliciting an action potential (Bikson et al., 2004). During an action potential, a change in voltage across the membrane is caused by the flow of ions such as potassium, sodium, and**

chloride into and out of the neuron. TDCS modulates the resting membrane potential of neurons by adjusting their state to approach or move away from the threshold potential (approximately -55mV) necessary to generate an action potential. In this manner, tDCS can enhance or diminish neuronal excitability. TDCS produces opposing effects on neuronal excitability depending on electrode polarity. Anodal tDCS (a-tDCS) is thought to cause neuronal depolarization which leads to an increase in neurons firing rate and excitability while cathodal tDCS (c-tDCS) is thought to cause neuronal hyperpolarization which leads to a decrease in neurons firing rate and excitability (Nitsche & Paulus, 2000; Yamada & Sumiyoshi, 2021). Although anodal stimulation often led to performance enhancement, the effects from cathodal stimulation were relatively inconsistent (Jacobson et al., 2012).

Improvement in own-race face processing has been found following the application of a-tDCS to the occipital area (Barbieri et al., 2016) and, more specifically, to the fusiform face area (Brunyé et al., 2017). For example, participants who received online (i.e., stimulation applied during task execution) 1.5mA of a-tDCS to the right fusiform gyrus (i.e., PO10) during both study and test phase showed improvement in face memory accuracy compared to participants who received 0.5mA of a-tDCS and participants who received no stimulation (Brunyé et al., 2017). Another study found that offline (i.e., stimulation applied before task execution) 1.5mA of a-tDCS to the right occipital cortex (i.e., PO8) improved face perception (measured by the Face Perception task) and face memory (measured by the Cambridge Face Memory Test) while no effect of online a-tDCS applied during both study and test phase was found (Barbieri et al., 2016). This showed that offline stimulation may work better compared to online stimulation in terms of improving face processing. However, the positive effects of a-tDCS on face identification are not always replicated (Willis et al., 2019).

In comparison to a-tDCS, research on the effects of c-tDCS on face identification is scarce (Costantino et al., 2017; Yang et al., 2014). One early study found that, compared to sham stimulation, both anodal and cathodal offline 1.5mA tDCS over occipito-temoporal regions (i.e., left occipito-temporal cortex: P7; right occipito-temporal cortex: P8) reduced the N170 face-specific event-related potential component (Yang et al., 2014). The findings of this study showed that the polarity of the current

did not alter the effect of the stimulation, suggesting that anodal and cathodal tDCS elicit similar effects, at least in the face domain. A more recent study found that **offline** 1.5mA of c-tDCS over the right occipital cortex **(i.e., PO8)** could decrease recognition performance for other-race faces (Costantino et al., 2017). Specifically, this study tested a group of non-Caucasian participants who lived in a Caucasian-majority country and had extensive experience with Caucasian faces. Interestingly, after c-tDCS, performance to identify Caucasian faces decreased in the non-Caucasian group, suggesting that c-tDCS elicited an ORE-like behaviour.

However, Costantino et al's. (2017) study presents a few important methodological drawbacks. **In the study, stimulation was a between-subjects variable where participants either received sham stimulation or c-tDCS. However,** while the pre-stimulation **assessment** comprised a face perception test (i.e., Cambridge Face Perception Test, Duchaine et al., 2007), the post-stimulation **assessment** comprised a face memory test (i.e., the Cambridge Face Memory Test, Duchaine & Nakayama, 2006). Interestingly, research has shown that face perception **(i.e., face identification without memory component)** and face memory **(i.e., face identification with memory component)** are only moderately correlated (Bate et al., 2019; Verhallen et al., 2017) and dissociations between these two skills have been previously reported (Barton, 2008; Behrmann et al., 2005; Dalrymple, Garrido, et al., 2014; Estudillo & Bindemann, 2014; Weigelt et al., 2014). **Therefore, it is possible that there may be pre-stimulation differences in face memory performance between the c-tDCS and the sham stimulation groups which could potentially explain any post-stimulation differences.** In addition, Costantino et al. (2017) only used c-tDCS, so it is unknown whether anodal stimulation would produce similar effects in other-race faces.

Present study

The current study aims to further investigate the effect of anodal and cathodal tDCS on the recognition of own- and other-race faces. The stimulation will be applied in an offline manner since previous research using transcranial electrical stimulation has shown that offline stimulation is more effective compared to online stimulation **in the working memory (Friehs & Frings, 2019) and face**

identification domain (Barbieri et al., 2016; Estudillo et al., 2023), at least in the neurotypical population (Hill et al., 2016). The ability to recognize own- and other-race faces will be assessed before the stimulation sessions to ensure that there are no differences in general face recognition ability between the stimulation groups. To assess face recognition ability, we employed the same face memory measure (the Cambridge Face Memory Test) before and after stimulation. Furthermore, both a-tDCS and c-tDCS will be included to compare the effects of these two forms of stimulation. As previous work examining the tDCS effects on face processing showed inconsistent findings (Barbieri et al., 2016; Costantino et al., 2017; Willis et al., 2019; Yang et al., 2014), we based our hypothesis on the neurophysiological mechanism of tDCS (Nitsche & Paulus, 2000) where a-tDCS should improve the recognition of own- and other-race faces while c-tDCS should impair the recognition of own- and other-race faces.

Methods

The experiment was pre-registered via the Open Science Framework (OSF) before data collection (https://osf.io/6cf7w).

Participants

A power sensitivity analysis conducted using G*Power 3.1 (Faul et al., 2009) revealed that a 2 (CFMT type: own-race vs. other-race) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) mixed ANOVA with 90 participants would be sensitive to effects of $\eta^2 = .015$, $f = .124$ with 80% power (alpha = 0.5). This means the study would not be able to reliably detect effects smaller than $\eta^2 = .015$. The effect size reported in Costantino et al. (2017) was $\eta^2 = .037$, $f = .196$, which exceeds the detectable effect size in the current study.

Ninety Chinese Malaysian (67 females) were recruited. Participants' age ranged between 18 and 28 years (M = 21.11 years, SD = 1.97 years) and were students at the University of Nottingham Malaysia. The participants were assigned randomly to one of three stimulation conditions: a-tDCS, c-tDCS or sham

stimulation, with 30 participants in each condition. One-way ANOVA revealed no age difference between stimulation groups, $F(2, 87) = 1.9$, $p = .16$. Prior to the experimental session, all participants completed a screening form regarding the inclusion and exclusion criteria concerning the application of transcranial electrical stimulation and provided informed consent. Participants were asked to sleep for a minimum of six hours and refrain from consuming alcohol (one day before the experimental session) and caffeine (one hour before the experimental session). Participants were also asked to avoid using any hair products (i.e., hair cream, hair gel) on the day of the experimental session. Since hormone levels which fluctuate among females due to the menstrual cycle could affect cortical excitability (Smith et al., 2002), female participants were only recruited during the follicular phase of the menstrual cycle, as in this phase the hormone levels are most similar to males (for a similar procedure, see Barbieri et al., 2016).

A remuneration of RM20 was given for participation. The study has been reviewed and approved by the Science and Engineering Research Ethics Committee (SEREC) at the University of Nottingham Malaysia (approval code: KSK050320).

Cambridge Face Memory Test (CFMT)

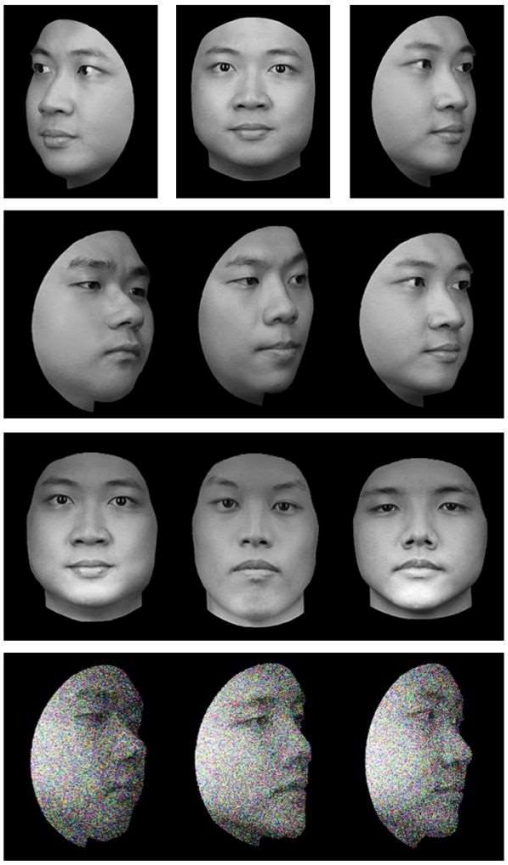
Two versions of the own-race CFMT (i.e., CFMT-Chinese, McKone et al., 2017) and CFMT-Chinese Malaysian, Kho et al., 2023) and two versions of the other-race CFMT (i.e., CFMT-original, Duchaine & Nakayama, 2006, and CFMT-Australian, McKone et al., 2011) were used in the experiment. The CFMT-Chinese Malaysian was designed to replicate the original CFMT using Chinese Malaysian faces and has recently been validated (Kho et al., 2023). The CFMT consists of three stages: learn (faces were presented with same light and viewpoint condition), novel (faces were presented with different light and viewpoint condition) and novel-with-noise (faces were presented with different light and viewpoint condition with Gaussian noise applied).

A total of six target faces were employed for the task. Only male identities were used in the task. This is because recognition performance between males and females is comparable for male faces, whereas females typically exhibit an advantage when recognizing female faces (Duchaine &

Nakayama, 2006; Lewin & Herlitz, 2002). Participants were given three practice trials before the actual trials to familiarize them with the procedure. In the learning stage (18 trials), three viewing angles of the target face were presented (frontal view, left 1/3 profile and right 1/3 profile) for three seconds each (Figure 1a). The target face was then presented with two distractor faces and participants were required to select the target face shown (Figure 1b). The distractors faces were selected based on their similarity in appearance to the target faces. The keys used to indicate the target face were "1" if the target face was the left image, "2" if it was the image in the middle and "3" if it was the right image with no time limit. In the novel stage (30 trials, Figure 1c) and novel-with-noise stage (24 trials, Figure 1d), participants were first instructed to memorize the same six target faces presented in the learning stage in frontal view for 20 seconds. Next, participants were required to select the target face presented with two distractor faces with no time limit during the test phase for the novel and the novel-with-noise stages.

Figure 1

Sample CFMT stimuli (images were not used in the actual task).



Three study images in learning stage presented in different views

Test trials in learning stage (faces are presented with same light and viewpoint condition as in study image)

Test trials in novel stage (faces are presented with different lighting and cropping template)

Test trials in novel-with-noise stage (faces are presented with different light and viewpoint condition with Gaussian noise applied)

Transcranial direct current stimulation (tDCS)

The stimulation was delivered using Starstim 8 (Starstim, Neuroelectrics, Barcelona, Spain). The electrodes were inserted into a neoprene cap in accordance with the international 10-10 EEG system. For the cathodal condition, 1.5mA was applied to PO8 (cathode) and FP1 (anode) by using a pair of surface sponge electrodes (25cm^2) soaked in saline solution (0.9% NaCl). Conversely, 1.5mA was applied to PO8 (anode) and FP1 (cathode) for anodal condition. The current was ramped up and down for the first and last 30 seconds for anodal and cathodal stimulation. In the sham condition, the stimulation was only delivered for the first and last 30 seconds to evoke the sensation of stimulation, without affecting neuronal excitability (Thair et al., 2017). The parameters of the stimulations were in accordance with the standard safety constraints (i.e., maximum total injected current: 4mA; maximum current for each electrode:

2mA). All stimulation conditions lasted for 20 minutes. Participants were monitored for any signs of distress at all times for safety purposes.

Procedure

The CFMT was presented using PsychoPy (Peirce et al., 2019). Own and other-race versions of the CFMT were counterbalanced across participants. Participants first completed one own- and one other-race CFMT as baseline tasks. The baseline tasks were included to ensure that there was no difference in individual face recognition ability between the stimulation groups prior to the stimulation.

Upon completing the baseline tasks, participants proceeded with the stimulation session. At the beginning of the stimulation session, a suitable neoprene cap size was selected based on the participant's head circumference measurement. Next, the location of stimulation was cleaned with alcohol solution using a cotton swab. The sponge electrodes were then fitted onto the neoprene cap and the electrical reference ear clip was fixed onto the participant's ear lobe. The impedance level was checked prior to the stimulation and monitored throughout the stimulation session. Participants received either sham stimulation, a-tDCS or c-tDCS for 20 minutes. A cartoon video was presented during the stimulation session to reduce inter-participant variability in visual sensation during the session (e.g., Renzi et al., 2015, for a similar procedure).

After the stimulation, participants completed the alternate versions of the own- and other-race CFMT. At the end of the experiment, participants were asked to complete a questionnaire related to tDCS sensations to check if there was any difference between the sensation perceived from a-tDCS, c-tDCS and sham stimulation. The experimental session lasted for approximately one and a half hours for each session.

Results

All data were analyzed using JASP version 0.16.3 (JASP Team, 2022).

Perceived sensation

Kruskal-Wallis test was conducted on the rating score (0 = none, 1 = mild, 2 = moderate and 3 = strong) of perceived sensation (itching, pain, burning, warmth/heat, and fatigue/decreased alertness) from the stimulation (a-tDCS vs. c-tDCS vs. sham stimulation). A difference in rating score of itching between stimulation type was found ($H(2) = 13.918$, $p < .001$). Post-hoc Dunn test showed that itching sensation for a-tDCS ($M = 1.633$, $SD = .890$) was higher than c-tDCS ($M = 1.233$, $SD = .774$), $p = .046$. Itching sensation for a-tDCS was also higher than sham stimulation ($M = .833$, $SD = .592$), $p < .001$. The post-hoc also showed that the itching sensation for c-tDCS was higher than sham stimulation, $p = .046$. No difference was found for rating score of pain ($H(2) = 1.233$, $p = .540$), burning ($H(2) = 1.851$, $p = .396$), warmth/heat ($H(2) = 4.791$, $p = .091$) and fatigue/decreased alertness ($H(2) = 1.002$, $p = .606$) between stimulation type. Kruskal-Wallis test also revealed no difference between stimulation type on the rating score for change in general state after stimulation (0 = not at all, 1 = slightly, 2 = considerably, 3 = much and 4 = very much), $H(2) = .744$, $p = .689$. For additional remarks on the sensation of stimulation and participants' beliefs about whether they had received real or sham stimulation, refer to Appendix A.

Baseline (pre-stimulation)

Accuracy is reported in proportion correct. **A one-way ANOVA revealed** no accuracy difference for own-race recognition between stimulation groups, $F(2, 87) = 1.532$, $p = .222$, $\eta^2 = .034$. **Bayesian analysis indicated that the null hypothesis (absence of accuracy differences between stimulation groups for own-race recognition) was 2.999 times more likely than the presence of accuracy differences between stimulation groups for own-race recognition ($BF_{01} = 2.999$, anecdotal evidence for null hypothesis). In terms of other-race recognition accuracy, a one-way ANOVA revealed a** significant effect of stimulation group, $F(2, 87) = 3.417$, $p = .037$, $\eta^2 = .073$. **Bayesian analysis revealed that the presence of accuracy differences between stimulation groups for other-race recognition were 1.455 times more favoured than the null hypothesis (absence of accuracy differences between stimulation groups for other-race recognition) ($BF_{10} = 1.455$, anecdotal evidence for alternative**

hypothesis). However, Holm's post hoc test reveal no difference between a-tDCS and c-tDCS (p = .915, BF_{01} = 3.794, moderate evidence for null hypothesis), a-tDCS and sham (p = .069, BF_{10} = 2.22, anecdotal evidence for alternative hypothesis), c-tDCS and sham (p = .069, BF_{10} = 2.399, anecdotal evidence for alternative hypothesis). Altogether, the results showed no difference in recognition ability for own- and other-race faces between stimulation groups prior to receiving stimulation.

Post-stimulation performance[1]

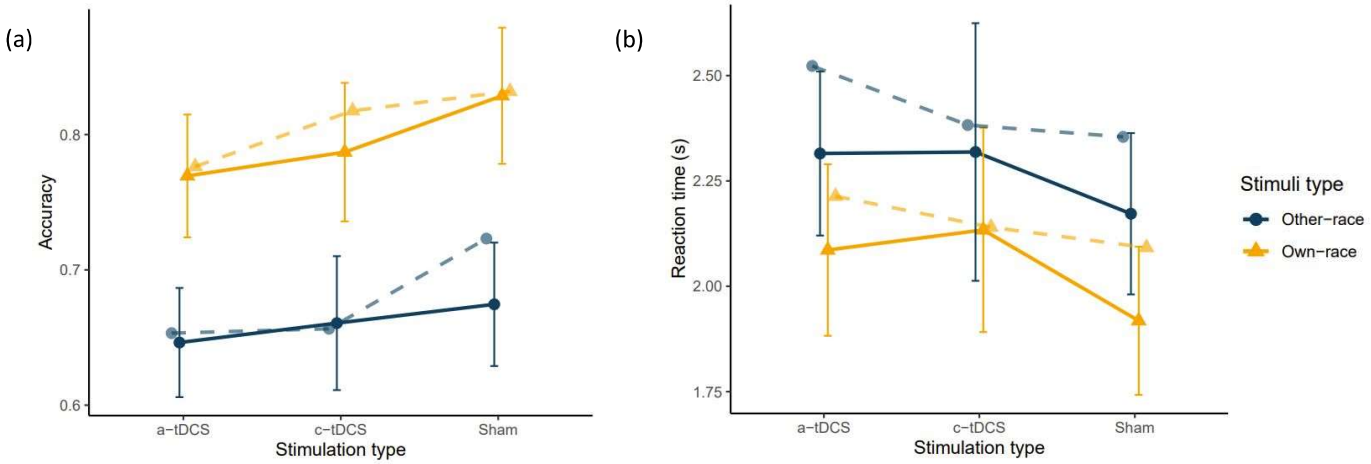
A mixed 2 (CFMT type: own-race vs. other-race) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA was conducted to examine if there was any difference in accuracy between stimulation groups (Figure 2a). Accuracy reported is in proportion correct. Analysis revealed no main effect of stimulation group on accuracy, $F(2, 87) = 1.093$, $p = .34$, $\eta_p^2 = .025$. Bayesian analysis indicated that the null hypothesis (absence of accuracy differences between stimulation groups) was 4.379 times more likely than the presence of accuracy differences between stimulation groups (BF_{01} = 4.379, moderate evidence for null hypothesis). A main effect of CFMT type was found, $F(1, 87) = 160.809$, $p < .001$, $\eta_p^2 = .649$, where own-race face recognition (M = .795, SD = .132) had higher accuracy compared to other-race face recognition (M = .660, SD = .121). Bayesian analysis revealed that the presence of accuracy differences in CFMT type were 2.401e + 18 times more favoured than the null hypothesis (absence of accuracy differences in CFMT type) (BF_{10} = 2.401e + 18, extreme evidence for alternative hypothesis). No significant interaction effect was found between stimulation group and CFMT type on accuracy, $F(2, 87) = .861$, $p = .427$, $\eta_p^2 = .019$. In line with this, Bayesian analysis showed that the null hypothesis (absence of interaction between stimulation group and CFMT type) was 4.238 times more favoured than the interaction between stimulation group and CFMT type (BF_{01} = 4.238, moderate evidence for null hypothesis).

[1] Results of analysis by stage (2 (CFMT type: own-race vs. other-race) × 3 (CFMT stage: learn vs. novel vs. novel-with-noise) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA) conducted on accuracy and reaction time are included in Appendix B.

A mixed 2 (CFMT type: own-race vs. other-race) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA was also conducted on correct median reaction times (Figure 2b). Analysis revealed no main effect of stimulation group on reaction time, $F(2, 87) = .892$, $p = .414$, $\eta_p^2 = .02$. **Bayesian analysis indicated that the null hypothesis (absence of reaction time differences between stimulation groups) was 2.532 times more likely than the presence of reaction time differences between stimulation groups ($BF_{01} = 2.532$, anecdotal evidence for null hypothesis).** A main effect of CFMT type was found, $F(1, 87) = 32.247$, $p < .001$, $\eta_p^2 = .27$, where own-race face recognition ($M = 2.046$s, $SD = .561$s) had shorter reaction time compared to other-race face recognition ($M = 2.269$s, $SD = .630$s). **Similarly, Bayesian analysis revealed that the presence of reaction time differences in CFMT type were 78786.398 times more favoured than the null hypothesis (absence of reaction time differences in CFMT type) ($BF_{10} = 78786.399$, extreme evidence for alternative hypothesis).** No significant interaction effect was found between stimulation group and CFMT type on reaction time, $F(2, 87) = .265$, $p = .768$, $\eta_p^2 = .006$. **Bayesian analysis showed that the null hypothesis (absence of interaction between stimulation group and CFMT type) was 6.431 times more favoured than the interaction between stimulation group and CFMT type ($BF_{01} = 6.431$, moderate evidence for null hypothesis).**

Figure 2

Accuracy (proportion correct) and median reaction time for correct trials in the stimulation groups, separated by own- and other-race CFMT versions. Post-stimulation measurements are represented by solid lines, while the pre-stimulation (baseline) measurements are shown with dotted lines.



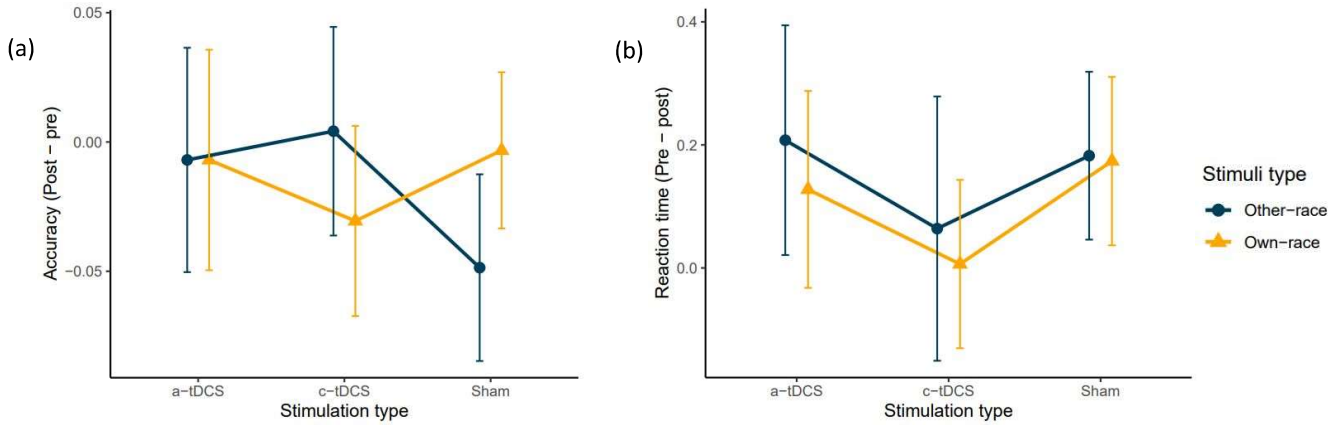
Note. Error bar represents 95% confidence interval.

To explore the change in performance as a consequence of stimulation type, we also calculated the difference in accuracy between post- and pre-stimulation for each stimulation group and CFMT type ($ACC_{Post} - ACC_{Pre}$). A higher value would indicate higher improvement in accuracy after stimulation. We analyzed these scores using a 2 (CFMT type: own-race vs. other-race) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA (Figure 3a). Analysis revealed no main effect of stimulation group, $F(2, 87) = .458$, $p = .634$, $\eta_p^2 = .01$, nor a main effect of CFMT type, $F(1, 87) = .063$, $p = .802$, $\eta_p^2 = .0007$, on accuracy improvement. **In line with this, Bayesian analysis showed that the null hypothesis was 8.696 times more favoured than the presence of accuracy improvement differences between stimulation group ($BF_{01} = 8.696$, moderate evidence for null hypothesis) and that the null hypothesis was 5.937 times more likely that the presence of accuracy improvement differences between CFMT type ($BF_{01} = 5.937$, moderate evidence for null hypothesis).** No significant interaction effect was found between stimulation group and CFMT type on accuracy improvement, $F(2, 87) = 2.688$, $p = .074$, $\eta_p^2 = .058$. **Bayesian analysis revealed that the null hypothesis (absence of interaction between stimulation group and CFMT type) was 13.21 times more favoured than the interaction between stimulation group and CFMT type ($BF_{01} = 13.21$, strong evidence for null hypothesis).**

We also calculated the difference in correct median reaction time between post- and pre-stimulation for each stimulation group and CFMT type ($RT_{Pre} - RT_{Post}$). A higher value would indicate higher improvement in reaction times after stimulation. We analyzed these scores using a 2 (CFMT type: own-race vs. other-race) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA (Figure 3b). Analysis revealed no main effect of stimulation group, $F(2, 87) = 1.782$, $p = .174$, $\eta_p^2 = .039$, nor a main effect of CFMT type, $F(1, 87) = .613$, $p = .436$, $\eta_p^2 = .007$, on reaction time improvement. **Bayesian analysis indicated that the null hypothesis was 3.409 times more favoured than the presence of reaction time improvement differences between stimulation group ($BF_{01} = 3.409$, moderate evidence for null hypothesis) and that the null hypothesis was 4.606 times more likely that the presence of reaction time improvement differences between CFMT type ($BF_{01} = 4.606$, moderate evidence for null hypothesis).** No significant interaction effect was found between stimulation group and CFMT type on reaction time improvement, $F(2, 87) = .114$, $p = .893$, $\eta_p^2 = .003$. **Similarly, Bayesian analysis revealed that the null hypothesis (absence of interaction between stimulation group and CFMT type) was 54.841 times more favoured than the interaction between stimulation group and CFMT type ($BF_{01} = 54.841$, very strong evidence for null hypothesis).**

Figure 3

Change in accuracy (post- minus pre-stimulation) and median reaction time for correct trials(pre- minus post-stimulation) after stimulation, separated by stimulation group and own- and other-race CFMT versions.



Note. Error bar represents 95% confidence interval.

Discussion

This study aimed to investigate the effect of anodal and cathodal tDCS on the recognition of own- and other-race faces. Based on the neurophysiological mechanism of tDCS (Nitsche & Paulus, 2000), we expected to find an enhanced performance for own- and other-race face recognition following a-tDCS and a reduced performance for own- and other-race face recognition following c-tDCS. Our findings demonstrated that participants' post-stimulation performance was similar across all stimulation conditions (i.e., a-tDCS, c-tDCS and sham stimulation). In addition, there were no differences in the performance change (calculated using baseline and post-stimulation scores) between the different stimulation conditions. Thus, overall, our results showed no difference in accuracy and reaction time for own- and other-race face recognition after either a-tDCS, c-tDCS or sham stimulation.

Contrary to our expectation, a-tDCS did not improve own- or other-race face recognition. Our findings are in line with past work which have reported null effects of a-tDCS on the occipital region involved in face processing (Willis et al., 2019). Interestingly, although the same stimulation protocol (i.e., 20 minutes of offline 1.5mA of tDCS to the occipital region delivered using a 25cm^2 sponge electrode) and face recognition measure (i.e., CFMT) were used in the current experiment and Barbieri et al. (2016), we failed to replicate the face memory improvement effect found in their experiment. We also found no impairment of own- or other-race face recognition after c-tDCS. This is in line with previous

work suggesting that the effects from cathodal stimulation are relatively inconsistent (Jacobson et al., 2012). However, this contradicted findings by Costantino et al. (2017) where they suggested that c-tDCS impaired the recognition of other-race faces. In this study, we used the same stimulation protocol and face recognition measure as Costantino et al. (2017). In addition, we also used more comparable measures across baseline and post-stimulation tasks (i.e., different versions of the CFMT). However, we failed to replicate the impairment of other-race recognition reported by Constantino et al. (2017). Our findings are in line with past studies showing that cathodal stimulation does not always lead to a decrease in neuronal excitability and performance (Horvath et al., 2015; Wiethoff et al., 2014), and that its effects on cognition can be inconsistent (Jacobson et al., 2012).

Overall, our findings support past research showing that the effect of a-tDCS and c-tDCS may not always be reliable (López-Alonso et al., 2014; Strube et al., 2015; Wiethoff et al., 2014). For example, it has been reported that more than half of the participants (55%) did not show the expected excitatory effect on neuronal excitability after a-tDCS whereas the remaining 45% showed the expected excitatory effect (López-Alonso et al., 2014). In line with this, a different study reported that 50% of the participants showed little or no response to tDCS whereas the remaining participants responded similarly to both c-tDCS and a-tDCS (Wiethoff et al., 2014). Thus, it could be that the participants in our experiment were less responsive to tDCS leading to the null effects of both a-tDCS and c-tDCS on the face recognition tasks.

In fact, the inter-individual differences in the tDCS effects is a known limitation of tDCS studies. The lack of stimulation effect could be attributed to differences in the biological substrate such as the pre-existing neurotransmitter levels and differences in head size and scalp thickness (Krause & Cohen Kadosh, 2014; Laakso et al., 2019). Therefore, some participants might have received more or less stimulation effect than others, leading to variability in the effectiveness of tDCS. This issue, however, could not be resolved by implementing a within-subjects design as past work has also shown intra-individual differences in the effect of tDCS where the effect of tDCS varies across different test sessions

(Dyke et al., 2016). Hence, intra- and inter-individual differences may have contributed to the inconsistent findings of tDCS studies.

In addition, the lack of stimulation effect observed in our study may be due to the low focality of stimulation to the target area, which is a common limitation of tDCS studies that use a traditional two-electrode montage. Research by Barbieri et al. (2016) found that this type of stimulation did not produce face-specific effects, as it improved both face and object memory. In contrast, research targeting the FFA with high-focality stimulation have shown selective enhancement of face memory (Brunyé et al., 2017). The low focality stimulation used in our study may have resulted in current spreading to non-target regions, leading to noise in the data. To address this limitation, future studies could use high focality stimulation techniques such as high-definition tDCS (Datta et al., 2009; Kuo et al., 2013; Villamar et al., 2013) or multifocal tDCS (Fischer et al., 2017), which rely on smaller electrodes to increase focality and reduce current spread to non-target regions.

To conclude, we found no effect of a-tDCS and c-tDCS in the recognition of own- and other-race faces. Our findings showed that the effects of anodal and cathodal tDCS may not always be reliable and support the inconsistency of tDCS effects in face processing (Willis et al., 2019). This is consistent with the increasing number of studies that have failed to replicate the positive effects of transcranial electrical stimulation on mood and emotion (Koenigs et al., 2009), working memory (Nilsson et al., 2015, 2017; Westwood & Romani, 2018), verbal fluency (Vannorsdall et al., 2016; Westwood & Romani, 2018), reading (Cummine et al., 2020), sustained attention (Jacoby & Lavidor, 2018) and spatial attention (Learmonth et al., 2017).

Declarations

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Conflicts of interest/Competing interests

The authors report there are no competing interests to declare.

Ethics approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Science and Engineering Research Ethics Committee (SEREC) at the University of Nottingham Malaysia (approval code: KSK050320).

Availability of data and materials

The data that support the findings of this study are openly available in Open Science Framework (OSF) at https://osf.io/8t4zr/?view_only=654e85d7b3db43f38bf97385bea11a8e.

Authors' contributions

The authors confirm contribution to the paper as follows: study conception and design: Siew Kei Kho and Alejandro J. Estudillo; data collection: Siew Kei Kho; analysis and interpretation of results: Siew Kei Kho and Alejandro J. Estudillo; draft manuscript preparation: Siew Kei Kho, David R. T. Keeble, Hoo Keat Wong, and Alejandro J. Estudillo. All authors reviewed the results and approved the final version of the manuscript.

Open Practices Statements

The data for the experiment are available in Open Science Framework (OSF) at https://osf.io/8t4zr/?view_only=654e85d7b3db43f38bf97385bea11a8e and the experiment was preregistered via the OSF before data collection (https://osf.io/6cf7w).

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Appendix A

Table 1

Additional remarks on the sensation of stimulation.

Stimulation	Additional remarks
a-tDCS	Random electrical pinch on wrist
	Very slight itch experienced
	Fatigue (3 participants)
	I felt a little sleepy half way of watching the video
	Slightly more alert
	I had a slight decrease in terms of awareness. Mild dizziness starting only towards the end of the video.
c-tDCS	Less focus and face recognition skills reduced
	Fatigue
	Feeling a little bit sleepy, but otherwise no difference to usual tiredness before bed time
	Felt fatigue in the middle of the experiment
	Pin prickling sensation
Sham stimulation	Dizzy
	Feeling a bit tired and loss of focus after the stimulation
	Not much sensation from the device but feeling a bit dizzy at the initial moment

	I felt the itching at the beginning and the end, not in the middle

Note. Remarks provided by 17 participants

Table 2

Participants' beliefs about whether they had received real or placebo stimulation.

	Number of participants		
Stimulation	Real	Placebo	Not sure
a-tDCS	21	3	6
c-tDCS	17	1	12
Sham stimulation	15	4	11

Note. Each stimulation group had 30 participants.

Appendix B

Mixed ANOVA was conducted to examine difference in accuracy and median reaction time for correct trials for own- and other-race CFMT task among the stimulation groups (a-tDCS vs. c-tDCS vs. sham stimulation). When Mauchly's test indicated that the assumption of sphericity had been violated, the degrees of freedom was corrected using Greenhouse-Geisser estimates of sphericity.

Accuracy

A mixed 2 (CFMT type: own-race vs. other-race) × 3 (CFMT stage: learn vs. novel vs. novel-with-noise) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA was conducted to examine if there was any difference in accuracy between stimulation groups. Accuracy reported is in proportion correct. Analysis revealed no main effect of stimulation group on accuracy, $F(2, 87) = 1.152$, $p = .321$, $\eta_p^2 = .026$. A main effect of CFMT type was found, $F(1, 87) = 171.982$, $p < .001$, $\eta_p^2 = .664$, where own-race face recognition ($M = .795$, $SD = .132$) had higher accuracy compared to other-race face recognition ($M = .660$, $SD = .121$). No significant interaction effect was found between stimulation group and CFMT type on accuracy, $F(2, 87) = .737$, $p = .481$, $\eta_p^2 = .017$.

A main effect of CFMT stage was found, $F(1.562, 135.921) = 389.430$, $p < .001$, $\eta_p^2 = .817$. Post-hoc Holm–Bonferroni test revealed that the learning stage ($M = .958$, $SD = .068$) had higher accuracy compared to the novel stage ($M = .685$, $SD = .178$), $p < .001$, $d = 1.894$. The learning stage also had higher accuracy compared to the novel-with-noise stage ($M = .608$, $SD = .210$), $p < .001$, $d = 2.430$. Accuracy for novel stage was higher compared to novel-with-noise stage, $p < .001$, $d = .536$. No significant interaction effect was found between stimulation group and CFMT stage on accuracy, $F(4, 174) = .846$, $p = .498$, $\eta_p^2 = .019$.

A significant interaction effect was found between CFMT type and CFMT stage on accuracy, $F(2, 174) = 94.308$, $p < .001$, $\eta_p^2 = .520$. Simple main effect analysis revealed that scores of the own-race CFMT was higher than other-race CFMT in the learning stage (own-race: $M = .967$, $SD = .063$, other-race: $M = .949$, $SD = .071$), $F(1, 89) = 4.961$, $p = .028$, $\eta^2 = .053$, novel stage (own-race: $M = .743$, SD

= .181, other-race: M = .627, SD = .156), $F(1, 89) = 51.356$, $p < .001$, $\eta^2 = .366$, and novel-with-noise stage (own-race: M = .731, SD = .174, other-race: M = .486, SD = .167), $F(1, 89) = 262.331$, $p < .001$, $\eta^2 = .747$. No significant interaction effect was found between stimulation group, CFMT stage and CFMT type on accuracy, $F(4, 174) = 1.431$, $p = .226$, $\eta_p^2 = .032$.

Reaction time

A second mixed ANOVA was conducted to examine if there were any difference in median reaction time for correct trials between stimulation group. Analysis revealed no main effect of stimulation group on reaction time, $F(2, 87) = .953$, $p = .390$, $\eta_p^2 = .021$. A main effect of CFMT type was found, $F(1, 87) = 47.650$, $p < .001$, $\eta_p^2 = .354$, where own-race face recognition (M = 2.046s, SD = .561s) had shorter reaction time compared to other-race face recognition (M = 2.269s, SD = .630s). No significant interaction effect was found between stimulation group and CFMT type on reaction time, $F(2, 87) = .036$, $p = .964$, $\eta_p^2 = .001$.

A main effect of CFMT stage was found, $F(1.659, 144.348) = 98.913$, $p < .001$, $\eta_p^2 = .532$. Post-hoc test revealed that the learning stage (M = 1.639s, SD = .488s) had shorter reaction time compared to the novel stage (M = 2.534s, SD = .849s), $p < .001$, $d = 1.275$. The learning stage also had shorter reaction time compared to the novel-with-noise stage (M = 2.547s, SD = 1.120s), $p < .001$, $d = 1.293$. No difference was found in reaction time for novel and novel-with-noise stage, $p = .867$, $d = .018$. No significant interaction effect was found between stimulation group and CFMT stage on reaction time, $F(4, 174) = 1.415$, $p = .231$, $\eta_p^2 = .032$.

A significant interaction effect was found between CFMT type and CFMT stage on accuracy, $F(1.678, 145.977) = 4.823$, $p = .014$, $\eta_p^2 = .053$. Simple main effect analysis revealed that reaction time of the own-race CFMT was shorter than other-race CFMT in the learning stage (own-race: M = 1.545s, SD = .439s, other-race: M = 1.732s, SD = .517s), $F(1, 89) = 28.026$, $p < .001$, $\eta^2 = .239$, novel stage (own-race: M = 2.396s, SD = .861s, other-race: M = 2.672s, SD = .819s), $F(1, 89) = 19.618$, $p < .001$, $\eta^2 = .181$, and novel-with-noise stage (own-race: M = 2.307s, SD = .803s, other-race: M = 2.786s, SD = 1.328s),

$F(1, 89) = 22.830$, $p < .001$, $\eta^2 = .204$. No significant interaction effect was found between stimulation group, CFMT stage and CFMT type on reaction time, $F(4, 174) = .384$, $p = .820$, $\eta_p^2 = .009$.