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Modulate the Face Inversion Effect (FIE): Using transcranial Direct Current Stimulation (tDCS) to reduce and enhance the FIE.

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Abstract

We report a large study (n=120) investigating the effects of tDCS at Fp3 on the FIE. We used a double-blind design with subjects randomly assigned to one of the three tDCS groups and then engaged with a recognition task involving upright and inverted faces. Group 1 (control), subjects first received sham tDCS in the study phase (learning) followed by sham tDCS in the recognition phase; Group 2, subjects received anodal tDCS in the study phase followed by sham tDCS in the recognition phase; Group 3, subjects received anodal tDCS in the study phase followed by cathodal tDCS in the recognition phase. Group 2's results confirmed that anodal tDCS reduces the FIE vs. sham (Group 1) by disrupting performance for upright faces. Importantly, Group 3's results revealed that cathodal tDCS applied after anodal, increased the FIE vs. Group 2, bringing it back to control, by enhancing performance for upright faces. These results reveal that the negative effects of anodal tDCS on the FIE can be reversed by cathodal tDCS.

Keywords: Face Recognition; Face Inversion Effect; Perceptual learning; tDCS

Introduction

The face inversion effect (FIE) refers to a defection in recognition performance when we are presented with inverted upside-down faces compared to when the same faces are presented in their usual upright orientation (Yin, 1969). When it was fist discovered, this robust phenomenon was used as an index of the specificity-based nature of face recognition mechanisms. This was because a larger inversion effect was found for faces than for other sets of stimuli (e.g., houses, cars) (Yin, 1969; Valentine 1988; Civile et al., 2014; Civile et al., 2016; Maurer et al., 2002; McCourt et a., 2023). This was later challenged by authors who demonstrated that a robust inversion effect as that for faces, could be obtained with dog images if the subjects were dog breeders (i.e., experts) (Diamond and Carey 1986). This was the first robust evidence in support of the inversion effect being based on perceptual expertise rather than the specificity of faces. In 1997, two key studies in the literature provide further evidence for the perceptual expertise account. Gauthier and Tarr (1997)'s work showed how having been familiarised with categories of artificial stimuli (Greebles) would lead to an advantage in recognition performance when the stimuli are presented upright but not when presented inverted. In the specific task, subjects were asked to detect a Greeble's part inserted within the context of a familiar Greeble, or a manipulated Greeble, or the isolated part alone. The results revealed that subjects were better at detecting the part when presented within the familiar Greeble's configuration shown upright. Despite the inversion effect not being measured directly, this study was one of the first demonstrations that pre-exposure to stimuli never seen before entering the lab, would lead to a benefit in performance when presented in the familiarised upright orientation. In a similar vein, McLaren (1997) demonstrated how pre-exposure to prototype-defined categories of non-mono-orientated (i.e., no predefined orientation) artificial stimuli (checkerboards) would lead to an inversion effect tested through a matching task. More recently, Civile, Zhao et al (2014) extended McLaren's (1997) work by using the same checkerboard stimuli in an old/new recognition task typically used in the face recognition literature to test the inversion effect. The results revealed a robust inversion effect for checkerboards drawn from a familiar category vs. those drawn from a novel (control) category (see also McLaren and Civile, 2011). These findings were interpreted using the MKM model (McLaren et al 1989; McLaren and Mackintosh, 2000; McLaren et al., 2012) which is based on the modulation of salience by error to produce the type of perceptual learning at the basis of the inversion effect for checkerboards and by extension that for faces. According to this model when observers are first pre-exposed to the category exemplars, they would be more often focussed to the common features shared between the exemplars and the category prototype. Hence, these common features would be strongly associated with the category

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membership and would lose their salience (i.e., lower prediction error). However, the unique and unpredicted features specific to each exemplar would not suffer from this salience reduction. This feature salience modulation mechanism leads to perceptual learning, because now observers can focus instead on the unique features of each exemplar and can recognize exemplars from the same category when upright (the orientation familiarised during pre-exposure). On inversion, this learning mechanism based on previous experience would no longer apply because the unfamiliar spatial arrangement of the features renders those features less predicted by other features, and this would interfere with the salience modulation that is ordinarily in place between common and unique features of upright stimuli.

To further investigate the mechanisms at the basis of the inversion effect and how to modulate them, Civile, Verbruggen et al (2016) adapted a tDCS procedure previously used in the learning and categorization literature (Ambrus et al., 2011) to the Civile, Zhao et al (2014)'s checkerboard inversion effect paradigm. Ambrus et al (2011) used a bilateral bipolar-non-balanced montage with one electrode (anode) placed over the target stimulation area (Fp3, fMRI studies showed this area being highly activated in categorization learning tasks, Seger et al., 2000) and the other electrode (cathode/return) on the opposite supraorbital area (Fp2) while subjects completed a categorization learning task involving pattern configurations. The results revealed how active anodal tDCS reduced the prototype distortion effect. The results from Ambrus et al (2011) were then extended and confirmed by McLaren et al (2016) using the same tDCS montage applied to a categorization learning task involving the same prototype-defined checkerboards from Civile, Zhao et al (2014). In Civile, Verbruggen et al (2016) the same procedure applied to the checkerboard inversion effect showed anodal tDCS reducing the inversion effect vs. sham/control tDCS by means of disrupted recognition performance for upright familiar checkerboards. Hence, the same procedure was then extended to the FIE revealing how anodal tDCS reduced the FIE vs. sham/control tDCS and vs. an active control group (i.e., same behavioural task but different tDCS targeted area) by means of disrupted recognition performance for upright faces. The fact that the tDCS procedure affected similarly the inversion effect for checkerboards and faces suggested shared mechanisms at the basis of these effects constituting evidence in support of perceptual learning as one of the key factors determining the FIE. These findings were then replicated and further extended to tDCS and EEG combined to study the FIE, tDCS applied to normal vs Thatcherized face inversion effect, tDCS applied to the FIE as an index of the own-race bias (Civile, McLaren et al., 2019; Civile, Waguri et al., 2020; Civile, Cooke et al., 2020; Civile, McLaren et al., 2020; Civile and McLaren, 2022; Civile, Waguri et al., 2023). These effects of tDCS on the inversion effect have been explained based on the MKM model, hence, when the anodal tDCS is delivered, the reduced inversion effect is due to an impaired performance for upright stimuli because of the disruption of feature salience modulation. The anodal tDCS would disable the mechanism for salience modulation, so, instead of pre-exposure to enhance discriminability, it enhances generalization. Thus, common features (those shared across all exemplars) would be more prominent because they co-activate one another, whereas unique features would have low salience as they do not receive additional activation. It is this change in perceptual learning that reduces subjects' ability to discriminate between upright faces, essentially making the faces look more "similar" to one another thus resulting a reduced inversion effect. This explanation is also supported by the simulations work devised on a Matlab-based version of the MKM model that can simulate the tDCS effects on the inversion effect (Civile, McLaren et al 2023).

It is important to note the critical manipulations implemented to the specific tDCS montage and behavioural paradigm with the aim of advancing our understanding of how anodal tDCS over the Fp3 modulates the FIE. For instance, Civile, McLaren et al (2018, Experiment 3) conducted an active control study where the tDCS montage targeted a different scalp area (rIFG) to examine whether that would induce the same effects as those found for the anodal tDCS at Fp3 site. A robust FIE was found in both sham and anodal groups with no significant differences providing evidence that targeting any other scalp site would not induce the same tDCS effects as for the Fp3. Civile, McLaren et al (2021) also tested whether anodal stimulation over the PO8 site (based on ERPs work on the N170 component; Civile, Elchlepp, et al., 2018; Rossion et al., 2002; Busey and Vanderkolk 2005) would affect face recognition indexed by the composite face effect (better recognition of the top half of an upright face when conjoined with a congruent rather than incongruent bottom half). The PO8 was also the site selected by Yang et al (2014) and then Renzi et al (2015) to investigate the effects of anodal tDCS on the composite face effect. Despite Yang et al (2014) found some evidence for tDCS to modulate the composite face effect, Renzi et al (2015) failed to replicate that and found no effects of tDCS. Civile, McLaren et al (2021) found no effect of anodal tDCS at PO8 nor at Fp3 on the composite face effect. However, anodal tDCS at Fp3 reduced reliably overall recognition performance which was predicted since the task involved all upright faces. Finally, in a recent study the tDCS procedure was extended to a matching task able to ensure comparable levels of performance between face and checkerboard stimuli (Civile, Quaglia et al., 2021). The effects of anodal tDCS at Fp3 were confirmed showing a reduced inversion effect for faces and checkerboards vs. sham/control tDCS. As well for both sets of stimuli the reduced inversion effect in the anodal condition was mainly due to an impaired recognition performance for upright stimuli. Interestingly, by comparing the inversion effect between faces and checkerboards in the anodal groups it was found how the reduced but remaining FIE was significantly higher than the fully reduced checkerboard inversion effect. This suggested how different levels of expertise between faces and checkerboards or perhaps a face specificity component could be the driving factor between the fully reduced checkerboard inversion effect and the remaining FIE.

Overall, the results from the tDCS targeting the Fp3 site tells us that anodal stimulation reduces significantly the FIE by making recognition performance for upright faces worse. No effects were found on inverted faces. In the current study we extend this literature further by testing for the first time the effects on the FIE of the tDCS reversed polarity (cathodal stimulation) on the Fp3 site. From a theoretical point this study would address the account of reversibility of the tDCS effects. If the effects of anodal tDCS at Fp3 on the FIE can be "undone" we would rule out other explanations such as contextual or state change due to the anodal tDCS stimulation affecting either recognition directly or indirectly via an effect on perceptual learning. One example of this idea would be that the reduced FIE under anodal tDCS is due to a change of processing contingent on application of tDCS that occurs during the study phase, and this might negate the cumulative expertise built up over years of processing faces such that the participant is now effectively a novice, resulting in poorer performance to upright faces. This quite plausible explanation would be invalidated by reversing this effect with cathodal stimulation, because while that might return processing to normal - it would be too late if the faces had been encoded differently during the study phase. The mismatch between encoded stimulus during study and encoded stimulus at test would not be expected to boost performance back to normal levels. From a practical point, if cathodal tDCS can reverse the effects of anodal tDCS, we would have a lab-based tDCS paradigm able to fully modulate the FIE within-subjects by first making subjects worse at recognising upright faces and then bringing their performance back to normal.

Method

Subjects

Overall, 120 subjects (female=86, mean age= 20.3 years, age range=18-46 years) took part in the study, they were students at the University of Exeter and participated either for monetary compensation or course credit. All subjects were randomly assigned to one of the three tDCS (40 in each group). All methods were performed in accordance with the relevant guidelines and regulations approved by the CLES Psychology Research Ethics Committee at the University of Exeter. Informed consent was obtained from all subjects. The sample size was determined based on previous tDCS studies that have used the same old/new recognition paradigm, stimuli counterbalance, tDCS procedure and double-blind between-subject design (e.g., Civile, McLaren, et al., 2018; Civile, McLaren et al., 2019; Civile, Cooke, et al., 2020; Civile, Waguri, et al., 2020).

Materials

The study used a set of 128 male and 128 female face images standardized to grayscale on a black background taken from the Psychological Image Collection at Stirling open database (pics.stir.ac.uk). These face stimuli were the same as those used in previous tDCS and face inversion effect studies (e.g., Civile, McLaren et al., 2018; Civile, Waguri, et al., 2020; Civile, McLaren et al 2020). The stimuli, whose dimensions were 5.63 cm x 7.84 cm, were presented at a resolution of 1280 × 960 pixels. The experiment was run using Superlab 4.0.7b. on an iMac computer. Subjects sat about 70 cm away from the screen on which the images were presented.

TDCS apparatus and montage

The stimulation was delivered by a battery driven constant current stimulator (neuroConn DC-Stimulator Plus) using a pair of surface sponge electrodes (7cm x 5cm i.e., 35 cm^2) soaked in saline solution and applied to the scalp at the target areas of stimulation. We used a double-blind procedure reliant on the neuroConn study mode in which the experimenter inputs numerical codes (provided by another experimenter otherwise unconnected with running the experiment), that switch the stimulation mode between “active” (i.e., anodal or cathodal) and “sham” stimulation. In the anodal and cathodal conditions, a direct current stimulation of 1.5mA was delivered for 10 mins (5 s fade-in and 5 s fade-out) starting as soon as the participants began the computer tasks. The same tDCS setup and stimulation parameters were used in the anodal and cathodal conditions, except that the location of the two electrodes was swapped. Hence, in the anodal condition, in agreement with previous studies, we adopted a bilateral bipolar-non-balanced montage with one electrode (anode) placed over the target stimulation area (Fp3) and the other electrode (cathode/return) on the opposite supraorbital area (Fp2) above the right eyebrow (Civile, Verbruggen et al., 2016; Civile, McLaren et al., 2018; Civile, Obhi et al., 2019; Civile, Cooke et al., 2020; Civile, McLaren et al., 2021; Civile, Quaglia et al., 2021; Civile & McLaren 2022; Civile, McLaren et al., 2022; Civile, McLaren et al., 2023). In the cathodal condition, the cathode and anode electrodes were swapped so now the cathode was placed at Fp3 and the anode electrode was placed on the Fp2 serving as return channel. In the sham group (subjects split between the two anodal and cathodal tDCS setups), the identical stimulation mode was displayed on the stimulator and subjects experienced the same 5 s fade-in and 5 s fade-out, but with the stimulation intensity of 1.5mA delivered for just 30 s, following which a small current pulse was delivered every 550 ms (0.1mA over 15 ms) for the remainder of the 10 mins to check impedance levels (Figure 1a). Each subject received two tDCS sessions (in the study phase and in the recognition phase) for an overall of 20 min stimulation. Subjects were randomly assigned into three tDCS groups: **1)** Sham tDCS delivered during the study phase followed by sham tDCS delivered during the recognition task (i.e., control group); **2)** Anodal tDCS delivered during the study phase followed by sham tDCS delivered during the recognition task; **3)** Anodal tDCS delivered during the study phase followed by cathodal tDCS delivered during the recognition task.

The behavioural task

The behavioural paradigm in this experiment consisted of an old/new recognition task with the first round of stimulation delivered during the study phase and the second delivered during the recognition phase. The study phase was run over 128 trials, each one began a 1s fixation cue in the centre of the screen followed by a face image presented for 3s. The faces were split evenly between male and female upright and inverted and these were presented intermixed and in random order. No response was required from the subjects during the study phase, and they were asked to memorise as many of the faces as possible. Between phases subjects had a 5 min break while the second round of stimulation was setup and initiated, and the next phase (i.e., the recognition task) could begin. The recognition phase consisted of 256 trials, with 50% of those involving the stimuli from the study phase and 50% involving novel stimuli (also evenly split between upright and inverted orientations) presented one at a time at random order. Each trial began with a 1s fixation cue in the centre of the screen, followed by face stimulus shown for a maximum of 3s. Subjects responded using the "X" and "." keys to indicate whether they thought a given stimulus had been shown (i.e., 'old') or not (i.e., 'novel') in the study phase (the meaning assigned to the keys was counterbalanced across participant groups). If no response was given after 3s subjects were timed out and the next trial began automatically (Figure 1b).

Results

In agreement with previous studies (Civile, McLaren, et al., 2018; Civile, McLaren et al., 2019; Civile, Cooke, et al., 2020; Civile, Waguri, et al., 2020), here too our primary measure was performance accuracy in the old/new recognition task. Accuracy for male and female faces was collapsed based on previous studies that found no differences between them. The data from all the subjects in each experimental condition was used to compute a *d*-prime (*d'*) sensitivity measure for the recognition task where a *d*= of 0 indicates chance-level performance. We assessed performance against chance for upright and inverted faces in each tDCS group showing that for all conditions we found $p < .001$ for this analysis. Each p-value reported for the comparisons between conditions is two-tailed, and we also report the F or t value along with effect size (η^2p).

A 2x3 mixed model ANOVA was conducted with the within-subject factor *Orientation* (upright, inverted) and the between-subjects factor *tDCS Condition* (anodal-cathodal, anodal-sham, sham-sham). This revealed a significant main effect of *Orientation F*(1, 117)=87.08, p<.001, η^2_p=.427, demonstrating an overall inversion effect. There was no significant main effect of *tDCS Condition F*(1, 117)=2.08, p=.129, η^2_p=.034, indicating that tDCS does not have a blanker effect on overall performance (Civile, McLaren, et al., 2018; Civile, McLaren et al., 2019; Civile, Cooke, et al., 2020; Civile, Waguri, et al., 2020). Importantly, there was significant interaction between *Orientation* and *tDCS Condition F*(1, 117)=4.21, p=.017, η^2_p=.067.

Following this, independent t-tests were conducted to compare the size of the inversion effects (upright – inverted) in each tDCS group. There was a significant difference found in the inversion effect between the sham-sham condition and the anodal-sham condition, *t*(78)=2.10, p=.038, η^2p=.05, showing that in line with previous research, anodal tDCS reduces in the inversion effect Civile, McLaren, et al., 2018; Civile, McLaren et al., 2019; Civile, Cooke, et al., 2020; Civile, Waguri, et al., 2020). There was also a significant difference between the anodal-sham and anodal-cathodal condition *t*(78)2.64, p=.009, η^2p=.08, demonstrating that cathodal stimulation is able to counteract the reduction in the inversion effect that results from the anodal stimulation .There was no significant difference in the inversion effect between the sham-sham and anodal-cathodal conditions *t*(78)=.91, p=.36, η^2p=.01, indicating that cathodal stimulation can return performance back up to baseline following anodal stimulation. Additionally, performance for upright faces alone was compared across the tDCS groups based on the previous literature demonstrating that the tDCS procedure impacts upright but not inverted faces. In the anodal-sham condition performance for upright faces (M=.45, SE=.05) was significantly reduced compared to the sham-sham condition (M=.66, SE=.06), *t*(78)2.43, p=.017, η^2p=.07, and the anodal-cathodal condition (M=.69, SE=.07), *t*(78)=2.57, p=.012, η^2p=.07. There was no significant difference between the inverted faces in the anodal-sham condition (M=.23, SE=.05) compared to the sham-sham condition (M=.25, SE=.05), *t*(78)=.351, p=.73, η^2p<.01, or the anodal-cathodal condition (M=.19, SE=.04), *t*(78)=.588, p=.56, η^2p<.01 (Figure 2).

For completeness paired sample t-tests were conducted on the inversion effect for each tDCS group. The sham-sham group displayed the expected large inversion effect with performance for upright faces higher than for inverted faces (M(difference)=.41, SD=.37), *t*(39)=7.03, p<.001, η^2p=.56. In the anodal-sham condition a reduced but still significant inversion effect was found (M(difference)=.22, SD=.44) *t*(39)=3.18, p=.002, η^2p=.21. In the anodal-cathodal condition there was an inversion effect was found of similar size to the sham-sham condition (M(difference)=.51, SD=.52), *t*(39)=6.20, p<.001, η^2p=.49.

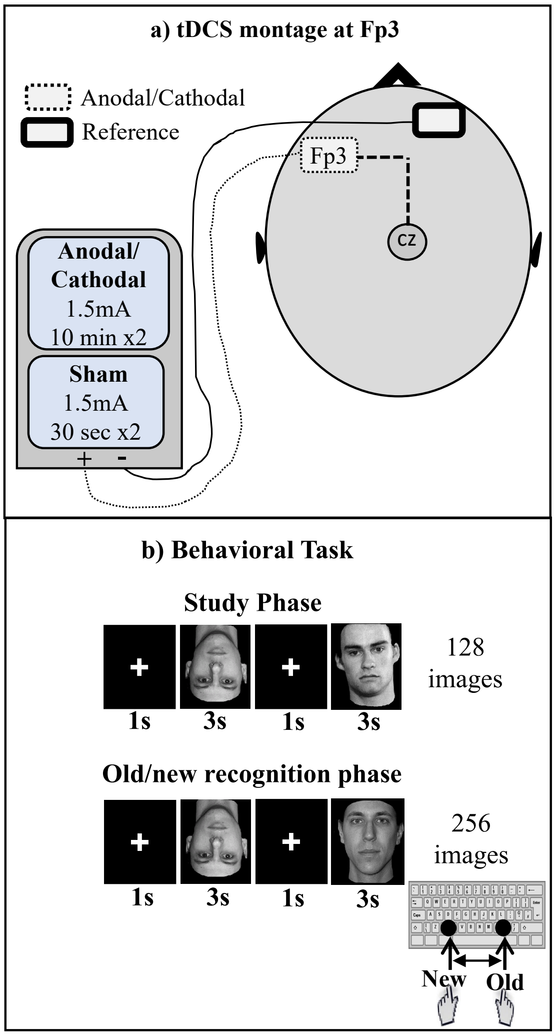

Figure 1. ***Panel a*** illustrates the tDCS montage adopted in our study. ***Panel b*** represents a schematic illustration of the behavioural task used in our study.

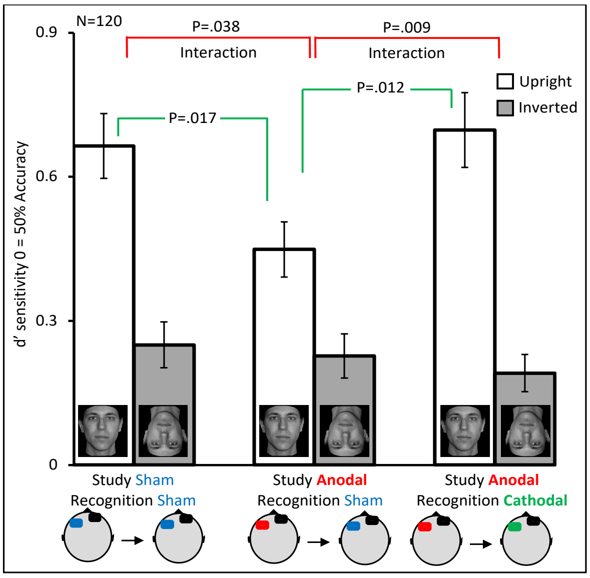

Figure 2 reports the results from our study. The x-axis shows the stimulus conditions across the three tDCS groups, the y-axis shows d'. Error bars represent s.e.m.

Performance for upright and inverted faces in all tDCS groups was significantly above chance (for all conditions we found $p < .001$ for this analysis).

Discussion

We report here the results from a large tDCS study that aimed to investigate if the reduction of the FIE after applications of anodal tDCS at Fp3, can then be reversed by using cathodal tDCS. The results from Group 2 confirmed what previously found in the literature. Hence, delivering anodal stimulation during the study phase leads to a significantly reduced FIE vs. that found in the control/sham group (Group 1). And, as for previous studies, in this case as well, the reduction of the FIE by means of anodal tDCS was mainly due to a significantly disrupted performance for upright faces. Thus, delivering anodal tDCS at Fp3 affects the FIE by making people worse at recognizing faces similarly to the effects found in individuals with prosopagnosia (face blindness) (Civile, McLaren et al., 2019; Civile, Waguri et al., 2020; Civile, Cooke et al., 2020; Civile, McLaren et al., 2020; Civile and McLaren, 2022; Civile, Waguri et al., 2023).

The new finding from our study is that from Group 3's results. Hence, we found that subjects who first received anodal tDCS (to induce the face recognition impairment) in the study phase and straight after received cathodal tDCS during the recognition phase did not show a reduction of the FIE nor an impairment in performance for upright faces. For them the FIE was recorded to be significantly larger than that found in Group 2 (anodal tDCS) and performance for upright faces was significantly better than that in Group 2. Critically, no difference was found between the FIE in Group 1 and 3 nor for upright faces. These results suggest that cathodal tDCS can reverse the negative effects that anodal tDCS induces on the FIE and recognition of upright faces. Hence, cathodal tDCS would seem to bring the FIE back to control mainly by repristinating performance for upright faces back to regular levels. This is an important finding because it advances our understanding of the effects of tDCS on perceptual learning indexed by the FIE. In particular, the fact that the negative effects of anodal tDCS at Fp3 can be reversed help us to exclude other explanations as those mentioned in the introduction. For instance, we can now exclude the idea that anodal tDCS changes the processing (and perhaps the face recognition scanpaths) that occurs during the encoding phase of the task (study phase). If that was the case, applying cathodal tDCS during the recognition task would be too late to reverse performance. Our results could be interpreted based on the MKM model of perceptual learning. Specifically, cathodal stimulation would be able to release the increased generalization induced by anodal tDCS by re-balancing the feature salience modulation mechanism. Hence, during anodal tDCS the salience of common features is kept relatively high making it easier for the observer to focus on the similarities between the faces (i.e., disrupting performance on a recognition task). However, when cathodal tDCS is then apply it stops the effects of anodal tDCS on the common features salience (which returns to low) and allows the observes to focus on the unique features typical of each face and useful to recognition. Future work needs to be conducted to characterise the effects of cathodal tDCS on the FIE for example when cathodal stimulation is delivered during the study phase (followed by sham in the recognition task).

Overall, our work extends the tDCS and perceptual learning literature by showing how cathodal stimulation can reverse the effects of anodal stimulation on the FIE. Importantly, this now gives us a tDCS paradigm that can, in the lab and within-subjects, first make people worse at recognizing faces, essentially inducing face-blindness, but later it can also make those same people good again at recognizing faces within an overall of 20 min of tDCS stimulation (10 min for anodal, and 10 min for cathodal). Thus, through tDCS we can now reduce and then enhance the FIE and recognition for upright faces.

More generally, our results contribute to a recent line of research investigating the effects of tDCS on perceptual learning, though these studies tend to differ in detail from our procedure. For instance, Pisoni et al (2015) showed that when anodal tDCS was administered at T3 scalp area performance at a face-name association learning task was significantly reduced vs. sham. In another study, Peters et al (2013) used anodal tDCS delivered on Oz scalp area while subjects performed, through two consecutive days, a detection task indicating the orientation of Gabor patches stimuli. The results revealed how performance improvement was found for subjects who received either cathodal or sham tDCS on the first day. No improvement was found for those who received anodal tDCS on the first day. The authors suggested how anodal tDCS at Oz impaired/blocked overnight consolidation of perceptual learning. Barbieri et al (2016) provided some evidence of how anodal tDCS at PO8 with the cathode/return electrode placed on the Fp1 led to an improved face and object recognition performance (inversion was not tested).

Finally, our results also contribute to the literature on tDCS and face recognition specifically. As mentioned in our introduction, Yang et al (2014) investigate the effects of anodal tDCS at P8 on face recognition performance as indexed by the size of the composite face effect which was found to be reduced. However, no specific statistical analyses were provided to reveal if the effects were due to an enhanced or reduced performance for any of the conditions used. Contrarily, Renzi et al (2015) found that anodal tDCS at OFA area did not modulate the composite face effect (similarly to Civile, McLaren et al 2021). However, when the same tDCS procedure was extended to Mooney faces (black and white distorted faces) a blocking learning effect was found at face detection (Renzi et al., 2015). Through additional post-hoc analyses Costantino et al (2017) revealed how cathodal tDCS at PO8 can induce effects like the own-race bias i.e., a reduced face recognition performance in non-Western Caucasian participants when asked to recognize Western Caucasian faces. More recently, Civile and McLaren (2022), provided the first evidence in the literature of how the own-race bias indexed by the FIE (i.e., larger FIE for own vs other-race faces) can be reduced after administering the anodal tDCS at Fp3. Western Caucasian participants in the active anodal stimulation group revealed a reduced FIE for own-race faces down to a similar level to that obtained for other-race faces, eliminating the own-race bias.

Taken together, our results and those from the studies reviewed here suggest that the use of tDCS can help us to modulate perceptual learning and face recognition thus advancing our understanding of the neurocognitive mechanisms at the bases of these important skills.

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