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Transcranial Direct Current Stimulation (tDCS) and the Face Inversion Effect: Anodal stimulation at Fp3 reduces recognition for upright faces

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Abstract

Perceptual learning is a key perceptual skill that people possess, in particular, it contributes to their ability to distinguish between faces thus recognize individuals. Recently, we showed that anodal *transcranial Direct Current Stimulation* (tDCS) at Fp3 abolishes the inversion effect (that would otherwise exist) for familiar checkerboards created from a prototype. Because of the close analogy between the inversion effect obtained with checkerboards, which we use as a marker for perceptual learning, and the traditional *face inversion effect* (upright faces recognized better than inverted ones), we investigated the effects of anodal tDCS at Fp3 during an *old/new recognition* task for upright and inverted faces. Results showed that stimulation significantly reduced the face inversion effect compared to controls. The effect was strongest in reducing recognition performance to upright faces. This result supports our account of perceptual learning and its role as a key factor in face recognition.

Keywords: TDCS; Perceptual learning; Face inversion effect; Old/new recognition task; Face recognition

Introduction

Perceptual learning refers to an enhanced ability to distinguish between similar stimuli as a consequence of experience with them or stimuli like them. It also plays a key role in learning to identify stimuli as specific exemplars of a category, and not confuse one stimulus with another similar one (e.g. wine experts and wines, or bird watchers and warblers; James, 1890; see Hall, 1980 for a review). We know that people (and other animals) can improve their perceptual skills as a result of experience with stimuli, and recent studies have shown this phenomenon to be responsible for some key perceptual skills that people possess. In particular, it contributes to our ability to distinguish between faces and recognize individuals. For example, if we pre-expose someone to a set of checkerboards, all of which are produced by imposing random variation on one original prototype checkerboard, then this will have the effect of making them better able to distinguish between exemplars generated in this way – a basic perceptual learning effect. They will now be able to tell two otherwise similar checkerboards apart where once they might have found it difficult to do so, and such *pre-exposure* improves their ability to identify checkerboards they have been asked to memorize in a subsequent recognition test (McLaren, Leevers & Mackintosh, 1994). McLaren (1997) extended this result to show that the same procedures could also produce an inversion effect, with upright exemplars discriminated better than inverted ones.

Civile et al. (2014) further developed the case for perceptual learning as a contributor to the *face inversion effect* (i.e. that upright faces are recognized much better than inverted ones), by showing that these results can be obtained with the kind of *old/new recognition* paradigm conventionally used in such studies (Yin, 1969; Diamond & Carey, 1986; see Maurer, Le Grand, & Mondloch, 2002 for a review). Participants were trained to categorize (categorization task) checkerboard exemplars from two prototype-defined categories (the pre-exposure phase), before being shown an equal number of checkerboard exemplars (which they had not previously encountered) drawn from either one of the now familiar categories or a novel category, half of which were upright and half inverted. Participants were then tested for recognition of these exemplars after this study phase. The results confirmed the inversion effect for checkerboard exemplars drawn from a familiar category, and its absence for exemplars drawn from a novel category, strengthening the case for perceptual learning contributing to the inversion effect found with faces.

In a recent study, Civile et al. (2016) demonstrated that tDCS to dorsolateral prefrontal cortex (DLPFC) at Fp3 site significantly affected perceptual learning and reduced the inversion effect that can otherwise be obtained with checkerboards. The authors adopted the same old/new recognition task as in Civile et al. (2014)'s study which uses a categorization task to pre-expose participants to the stimuli i.e. checkerboards. A previous study by Ambrus et al., (2011) had found that anodal tDCS (compared to sham) applied to the Fp3 during the training phase of a categorization task where participants had to identify prototype and low-distortion patterns as category members reduced classification accuracy for the prototype. Thus, as Civile et al. (2014)'s study used prototype-defined checkerboard categories and formation of a strong representation of the prototype is a prerequisite for perceptual learning (McLaren, Kaye, & Mackintosh,1989), Civile et al. (2016)'s study adopted the same Fp3 montage as that adopted by Ambrus et al. (2011). Civile et al. (2016) showed that the control condition (sham tDCS stimulation over Fp3 delivered during the *pre-exposure* phase, i.e. the checkerboard categorization task) replicated the usual inversion effect for checkerboards drawn from a familiar category, but, as expected, not for checkerboard exemplars drawn from a control (novel) category that had not been pre-exposed. Critically, anodal tDCS to the same brain region changed this pattern, as there was now no inversion effect for stimuli drawn from either familiar or unfamiliar category, and the upright exemplars drawn from a familiar category were less well recognized than those drawn from the novel category, an indication that perceptual learning may even have been reversed. This remarkable and informative result suggested that perceptual learning in humans could be turned 'on' and 'off".

Civile et al.'s (2016) study is the first evidence that anodal tDCS administered during the pre-exposure phase can affect perceptual learning later on when participants are asked to memorize and recognize exemplars of checkerboards drawn from the checkerboard categories seen in during the pre-exposure phase (categorization task). The next important question to address is whether or not the same tDCS procedure would also affect perceptual learning that has already taken place. Given the lifelong expertise we have for faces, and given the already established analogy between the inversion effect obtained with checkerboards (McLaren, 1997; McLaren & Civile, 2011; Civile et al., 2014; Civile et al., 2016) and that usually obtained with faces (for a review see Maurer et al., 2002), in the current study we extended the tDCS paradigm used in Civile et al.' (2016) to the inversion effect for faces. We expected to obtain a strong inversion effect for familiar faces in the sham tDCS group, but a significantly reduced inversion effect for familiar faces in the anodal tDCS group because, as was the case for Civile et al.'s (2016) familiar upright checkerboards, we expected anodal tDCS over Fp3 to disrupt recognition performance for familiar upright faces.

Such a result would advance our understanding of both the mechanisms controlling perceptual learning and the face inversion effect in a number of ways. We would have found an experimental procedure (anodal tDCS at Fp3 brain site) able to selectively affect perceptual learning and its expression, and this would help in discriminating between competing theories. Furthermore, we would have additional evidence that perceptual learning is a contributor (at least in part) to the face inversion effect. Finally, this would be the first demonstration in the literature of how relatively brief tDCS stimulation could reduce our ability to recognize upright familiar faces.

Method

We adopted the tDCS montage used in Civile et al. (2016). Each subject was randomly assigned to either sham or anodal tDCS conditions. In the sham condition, the tDCS stimulation was only delivered for 30s, to evoke the sensation of being stimulated, without causing neurophysiological changes that may influence performance. In the anodal tDCS condition, the stimulation was delivered for 10 mins while the subjects were completing an *old/new recognition* computer task that used images of faces. In both sample groups, the sham and tDCS stimulation started when the computer task began. In the first part of the computer task, the *study phase*, subjects were asked to memorize a set of upright and inverted faces presented one at a time. Following this, subjects were given a *recognition task* where they pressed one key if they thought they had seen the face before, and another key if they thought they had not seen the face before. All the faces seen in the study phase were presented again intermixed with an equal number of new faces of each type (i.e. upright faces, and inverted faces). This *old/new recognition task* is a standard method of assessing face processing and the inversion effect (Yin, 1969; Diamond & Carey, 1986; Civile, McLaren, & McLaren, 2016; Civile, McLaren, & McLaren, 2014). Our main measure was *accuracy* scores during recognition converted into signal-detection d-prime "d′". We also examined reaction time responses to check for any speed-accuracy trade-off that could affect our interpretation of the results.

Subjects

Forty-eight students (39 women; mean age = 18.9, age range = 18-22 years) from McMaster University participated in this experiment. Twenty-four subjects were randomly assigned to each of two groups (sham tDCS, anodal tDCS). All subjects were right-handed and were given course credits for their participation. The experiment was approved by the research ethics committee at McMaster University. Written informed consent was obtained after the nature and possible consequences of the study were explained. Sample size was determined in advance based on previous studies (Civile et al., 2014; McLaren 1997) that found the original inversion effect for checkerboards and that showed a clear effect of tDCS on perceptual learning (Civile et al., 2016; McLaren, Carpenter, Civile, McLaren, Zhao, Ku, Milton, Verbruggen, 2016), as well as previous studies that adopted the same old/new recognition task and face stimuli that we used here (Civile, McLaren, McLaren, 2014; and Civile, McLaren, McLaren, 2016 obtained a strong face inversion effect with group samples of 24 subjects). Additionally, we conducted a post-hoc power analysis using G*power software (Faul, Erdfelder, Lang, & Buchner, 2007) that revealed a statistical power of 0.92, in line with the recommended 0.80 level of power (Cohen, 1988).

Materials

The study used 128 images of male faces. Only male faces were used because they allowed the inclusion of ears in the images as well. Men tend to have shorter hair with ears visible whereas women often have longer hair covering the ears, making the visibility of these features rather variable. The faces were standardized in gray-scale format and cropped around the hairline in Adobe Photoshop. The same set of faces was previously used in studies that adopted the same *old/new recognition* task with upright and inverted faces that we used in the study here reported (Civile, McLaren, & McLaren, 2014; Civile, McLaren, & McLaren, 2016).

Transcranial Direct Current Stimulation (tDCS)

All participants first completed a brain stimulation safety screening questionnaire. Stimulation was delivered by a battery driven, constant current stimulator (Neuroelectrics) via a pair of surface sponge electrodes (25 cm^2), soaked in a saline solution (0.9% NaCl), and applied to the scalp at the target areas of stimulation. Electrodes delivered a constant current of 1.2 mA (current density: 0.048 mA/cm^2); the choice of the intensity is in line with Civile et al. (2016)'s study (see Neuroelectics website for a review of clinical studies that suggest keeping the average current densities in electrodes below 0.06 mA/cm2). As in Civile et al. (2016)'s study, we adopted a bilateral bipolar-non-balanced montage with one of the electrodes (anode/target) placed over the left PFC (Fp3) and the other (Ambrus et al., 2011; Kincses et al., 2003) was placed on the forehead, just above the right eyebrow. In the anodal tDCS condition, the current was applied for 10 mins (fade-in and fade-out of 5 s) from when the subjects began the computer task and throughout the *old/new recognition* task. Sham received the same 5 s fade-in and fade-out, but only 30 s stimulation between them, which terminated shortly after the computer task started. The electrodes were left on the participant throughout the experiment (see Figure 1, Panel A).

Behavioral Task

The *old/new recognition* task consisted of two parts: a 'study phase' and an 'old/new recognition phase' (Civile, McLaren, & McLaren, 2014; Civile, McLaren, & McLaren, 2016). In the study phase, each subject was shown upright and inverted faces with 32 images for each type (64 images in total). Faces were presented one at a time in random order. In the old/new recognition phase, 64 novel faces split into the same stimulus types were added to the 64 faces seen in the study phase, and all 128 images were presented one at a time in random order. Each face never appeared in more than one condition during the experiment for the same participant.

Trial Structure

Following the instructions, in each trial of the study phase subjects saw a fixation cross in the center of the screen presented for 1 second. After this, one of the faces was presented on screen for 4 seconds. The next trial started with the presentation of a fixation cross again. After all 64 faces had been presented, the program displayed another set of instructions, explaining the recognition task. In this task, subjects were asked to press the '.' key if they recognized the stimulus as having been shown in the study phase on any given trial, or press 'x' if they did not (the keys were counterbalanced). During the recognition task, the faces were shown for 4 seconds during which time subjects had to respond. The experiment was implemented using SuperLab 4.5 installed on a PC (see Figure 1, Panel B).

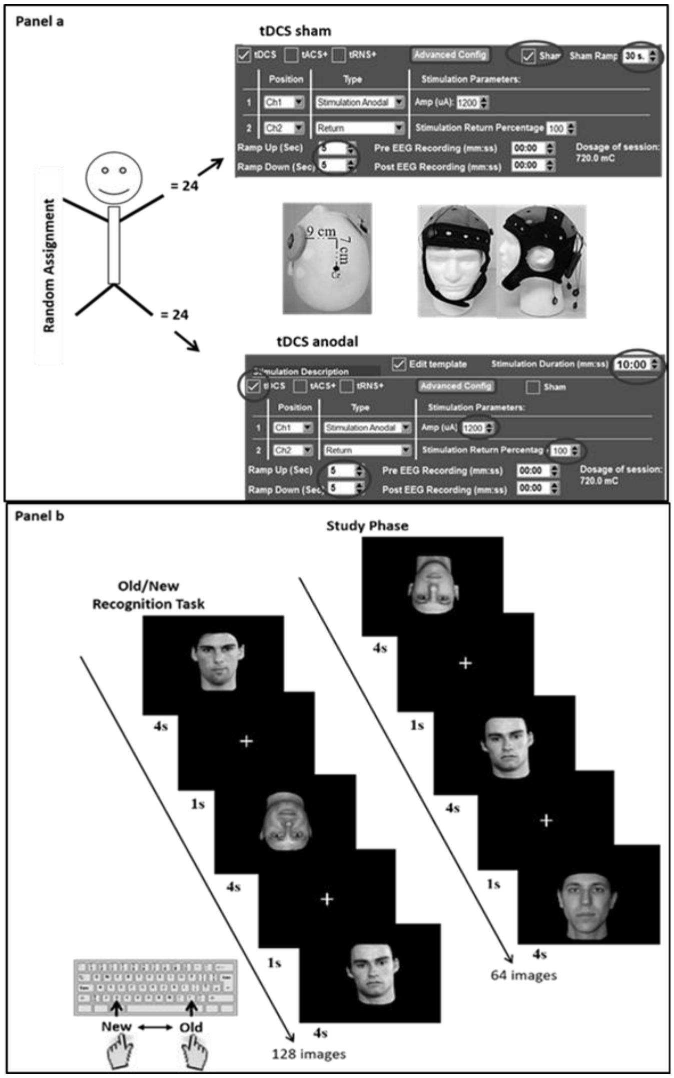

Figure 1: Panel a shows the electrode configuration of the tDCS and the stimulation set up on the Neuroelectrics software (NIC). Panel b shows the structure of the trials presented during the *old/new recognition* task.

Data Analysis

Our primary measure was performance accuracy in the two recognition tasks. The data from all the participants was used in the signal detection d' analysis of the recognition task (old and new stimuli for each stimulus type) where a d' = of 0.00 indicates chance-level performance (Stanislaw & Todorov, 1999). Each p-value reported in this paper is two-tailed, and we also report the F or t value along with measures of variability (SE or SEM) and effect size (Cohen's d followed by the 95% confidence interval [CI] for d). The study had a 2 x 2 mixed model design using as a within-subjects factor *Face Orientation* (upright, inverted) and the between-subjects factor *tDCS* (sham, anodal). Follow up, paired t-tests analyses were conducted to compare performance on upright and inverted faces (the inversion effect) in each tDCS group (sham, anodal). We also assessed performance against chance (d' of 0) to show that both upright and inverted faces in the tDCS sham and anodal groups were recognized (for all four conditions we found a $p < .001$).

Results

The statistical analysis (ANOVA) using the factors *Face Orientation* (upright/inverted) x *tDCS* (anodal/sham) revealed a significant interaction, $F(1, 46) = 7.45$, $MSE = 0.12$, $p = .009$, $d = 0.78$, CI = 0.98, 0.58. We decomposed the interaction by looking at the inversion effect (upright faces – inverted faces) in each tDCS group (sham, anodal) separately. Following Civile et al's (2016) study, we expected to find the usual inversion effect for faces in the tDCS sham group. As predicted, a planned comparison showed a significant inversion effect with upright faces ($M = 1.09$, $SE = 0.11$) being recognized significantly better than inverted faces ($M = 0.35$, $SE = 0.07$), $t(23) = 7.48$, $SE = 0.09$, $p < .001$, $d = 1.59$, CI = 1.78, 1.41. Critically, we found a reduced (but still significant) inversion effect in the tDCS anodal group, recognition of upright faces ($M = 0.78$, $SE = 0.11$) compared to inverted faces ($M = 0.44$, $SE = 0.08$), $t(23) = 3.19$, $SE = 0.11$, $p = .004$, $d = 0.69$, CI = 0.89, 0.49 (see Figure 2). Thus, the inversion effect in the tDCS sham group was significantly greater than that in the tDCS anodal group, a similar result to that previously found in Civile et al. (2016)'s study using prototype-defined categories of familiar checkerboards.

Importantly, in Civile et al. (2016)'s study (Experiment 1) statistical analysis showed recognition of upright familiar checkerboards in the tDCS anodal group was reduced compared to that for familiar checkerboards in the tDCS sham group. We computed an additional analysis in our study to directly compare the recognition performance for upright faces in the two tDCS groups (sham, anodal). The results were that recognition for upright faces in the tDCS anodal group was reduced compared to that in the tDCS sham group, $t(46) = 1.95$, $SE = 0.14$, $p = .028$ (1-tail), $d = 0.56$, CI = 0.78, 0.34. Thus, in both Civile et al. (2016)'s study (Experiment 1) and in our current study, we have some evidence that anodal tDCS may affect the recognition of upright familiar stimuli (checkerboards in Civile et al, 2016, and faces in the current study). We calculated the Bayes factor using the procedures outlined by Dienes (2011) for this effect with faces using the effect for checkerboards in Civile et al. (2016)'s study (Experiment 1) as the prior, setting the standard deviation of p (population value |theory) to the mean for the difference between recognition for familiar upright checkerboards in the tDCS sham group vs that in the tDCS anodal group (0.359). We used the standard error and the mean difference for tDCS sham upright faces vs tDCS anodal upright faces effect found in our study and assumed a one-tailed distribution for our theory and a mean of 0. This gave a Bayes factor (B) of 3.65. This factor is greater than 3, providing good support for this component of the reduction in the inversion effect (for Bayes factor calculator see Dienes, 2011).

Statistical analysis (ANOVA) of the response latencies was also conducted. Simple comparisons showed a significant inversion effect for both Anodal ($p <.001$) and Sham ($p =.009$) groups, and the inversion effect was numericaly larger for the Anodal group, but no significant interaction ($p = .63$) was found. For completeness, we report the mean latencies for each stimulus condition: Sham upright faces, 1.37 s; Sham inverted faces, 1.47 s; Anodal upright faces, 1.48 s; Anodal inverted faces, 1.61 s.

Finally, we also report here the SDT Bias estimates for each of the four stimulus' conditions: Sham upright faces, β= 1.33; Sham inverted faces, β= 1.12; Anodal upright faces, β= 1.70; Anodal inverted faces, β= 1.04.

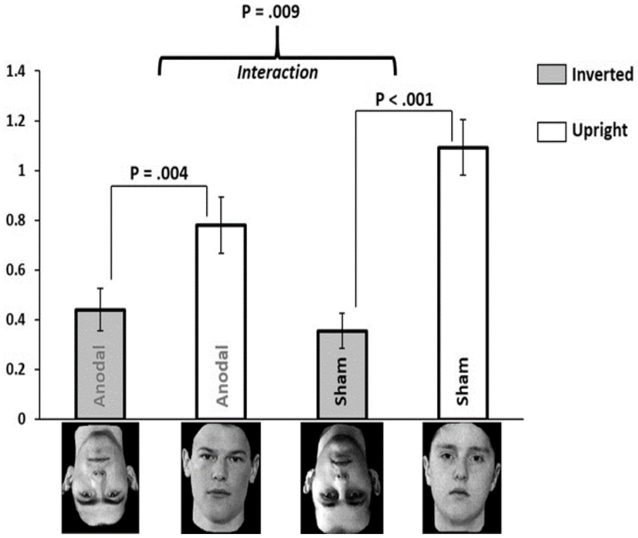

Figure 2: The *y*-axis gives d' means for the old/new recognition task (higher _ better, 0 _ chance), and the different stimulus' conditions in the two tDCS groups (sham, anodal) are shown on the *x*-axis. The dimensions of the stimuli were 6.95 cm × 5.80 cm. Participants sat 1 m away from the screen on which the images were presented.

Discussion

We adopted the same procedures used in Civile et al. (2016) employing the old/new recognition task for faces that is a standard in the literature. The results indicate that anodal tDCS impaired recognition performance for upright faces, and as a consequence, the inversion effect was significantly reduced compared to the usual inversion effect found with faces that can be seen in the sham condition.

The MKM model (McLaren, Kaye and Mackintosh, 1989) and its later development in McLaren and Mackintosh (2000) and McLaren, Forrest and McLaren (2014) can explain the inversion effects reported by McLaren (1997) and Civile et al (2014) by appealing to perceptual learning as a consequence of experience with the category. But if the salience modulation based on prediction error implemented by this model is disrupted (by anodal tDCS), then the MKM model turns into one more akin to McClelland and Rumelhart's (M&R) (1985) model of categorization, and enhanced generalization between exemplars as a consequence of familiarity with that category is predicted rather than the enhanced discriminability that is the hallmark of perceptual learning. The result is the elimination of the inversion effect seen with artificial stimuli (that we take to be entirely due to perceptual learning), and even some reversal of the perceptual learning effect, explaining the pattern observed by Civile et al (2016). This interpretation of the results from Civile et al. (2016)'s study also applies to Ambrus et al. (2011)'s finding that tDCS reduces learning to the prototype, and increases generalization to random patterns. This would result in the elimination of the prototype effect, which is what we would expect if the MKM model of perceptual learning were, in effect, to be turned into the M&R model of categorization by turning off the error-based modulation of salience that is the hallmark of MKM.

Our present data imply that anodal tDCS to Fp3 not only affects perceptual learning for artificial stimuli (the checkerboards in Civile et al., 2016) that were novel until encountered in the experimental setting but can also affect the long established perceptual learning for faces that is a result of experience over many years. This is a truly striking result that suggests that perhaps anodal tDCS over Fp3 may prevent individuals from exploiting "expertise" when called on to discriminate between stimuli of a class they are very familiar with.

These data strengthen the analogy between our checkerboard experiments and those with faces. In both cases, anodal tDCS reduces the inversion effect and reduces performance on upright exemplars taken from a familiar category. This suggests that the inversion effect obtained with what were novel, artificial stimuli, and that we attribute to perceptual learning, is at least one component of the face inversion effect. True, the inversion effect was completely eliminated by anodal stimulation in Civile et al (2016) but is still present in our stimulation group when we use faces. This could mean that any disruption of perceptual learning (which might be expected to be stronger after many years of experience) is not complete in the current experiment, or it might be that there is a component of the face inversion effect that is not due to perceptual learning. We cannot say at present. What we can say is that the theory we have of how anodal tDCS to Fp3 works predicted a reduced inversion effect, and our salience modulation via error account of perceptual learning is, to that extent, further validated. We have also shown that we can turn perceptual learning in humans on and off, which opens the door to future applications.

These data also contribute to a recent line of studies that tested that effects of tDCS stimulation delivered at occipital brain regions on face recognition tasks. In one study the authors tested tDCS stimulation on an orientation judgment task for faces while recording brain activity with EEG. Results showed that anodal tDCS compared to sham, significantly reduced the N170 for both upright and inverted faces, despite not affecting the size of the inversion effect (Yang et al., 2014, Experiment1). In the same study (Experiment 2) the authors also showed that the same tDCS paradigm applied before a composite face effect task (the effect refers to an impairment at recognizing the top half of a familiar face when matched with the bottom half of another face) can significantly reduce the composite effect by enhancing performance for incongruent faces (composite faces created by mismatched top and bottom halves). In a similar vein, another study found that off-line (stimulation delivered before the task) anodal tDCS enhances memory performance for both upright faces and objects (inversion was not tested). In contrast, no enhancement was found for online (stimulation delivered during task execution) and sham tDCS stimulation (Barbieri et al., 2016). Together, the results from these studies show that tDCS at occipital regions seems to be effective at enhancing recognition performance (at least when tDCS is delivered off-line). Thus, this suggests that tDCS at occipital brain regions could possibly enhance perceptual learning in our experimental paradigm (either with checkerboards or faces). Future studies should test this and directly compare the effect of tDCS at Fp3 with that of tDCS at occipital sites during (and off-line) using Civile et al. (2016)'s checkerboard paradigm and our face paradigm.

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