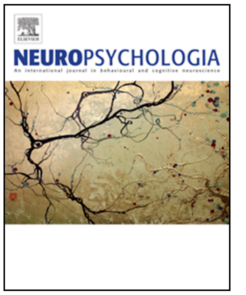

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Testing the effects of transcranial Direct Current Stimulation (tDCS) on the Face Inversion Effect and the N170 Event-Related Potentials (ERPs) Component.

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Abstract

The following study investigates the effects of tDCS on face recognition skills indexed by the face inversion effect (better recognition performance for upright vs. inverted faces). We combined tDCS and EEG simultaneously to examine the effects of tDCS on the face inversion effect *behaviourally* and on the N170 ERPs component. The results from two experiments (overall N=112) show that anodal tDCS delivered at Fp3 site for 10 min at 1.5mA (double-blind and between-subjects) can reduce *behaviourally* the face inversion effect compared to sham (control) stimulation. The ERP results provide some evidence for tDCS being able to influence the face inversion effect on the N170. Specifically, we find a dissociation of the tDCS-induced effects where for the *N170 latencies* the tDCS reduces the usual face inversion effect (delayed N170 in response to inverted vs. upright faces) compared to sham. Contrarily, the same tDCS procedure on the same participants increased the inversion effect seen in the *N170 amplitudes* by making the negative deflection for the inverted faces that much greater than that for upright faces. We interpret our results in the context of the literature on the face inversion effect and the N170 peak component. In doing so, we extend our results to previous studies investigating the effects of tDCS on perceptual learning and face recognition.

Keywords: Face Recognition; TDCS; EEG; Perceptual learning; Face Inversion Effect

Introduction

The face inversion effect refers to a reduction in performance when we try to recognize faces presented upside down compared to when we see them in their usual upright orientation (Yin, 1969; Civile, McLaren & McLaren, 2014). This is one of the most robust and replicated cognitive phenomenon that has been often used as an index of our face recognition skills. When it was first discovered, it was interpreted as a marker for the "specificity" of face recognition. This was because the effect was found to be larger for faces than for other visual stimuli such as houses or planes (Valentine & Bruce, 1986; Yovel & Kanwisher, 2005). However, in 1986 Diamond and Carey challenged the idea that faces are special and introduced "expertise" as a contributing factor to the inversion effect. The authors demonstrated that a large inversion effect, as that usually recorded for faces, can be obtained for dog images when participants were dog breeders (i.e. experts). Hence, they proposed that to recognize faces we rely on our experience with the configural information i.e. spatial relationships among the main features within a face. On inversion our ability to exploit such information is disrupted resulting in reduced recognition performance. A corollary of this position is that a robust inversion effect should be obtained for all those sets of stimuli that share a base configuration that we have the necessary expertise for.

Since Diamond and Carey' (1986) study, the term 'configural processing' has been used in the literature to refer to the perception of the spatial relationships among the main features within a stimulus such as a face. This term has often been deployed in contrast with 'featural processing' which instead refers to the perception of each specific feature in isolation from the rest of a face. Configural processing includes sensitivity to first-order relations (spatial relationships among the main features within a stimulus), and second-order relations (the variations in first-order relations relative to the prototype for that stimulus set). The same term can also include holistic processing, which refers to processing the stimulus as a gestalt (for a review see Maurer, Le Grand, & Mondloch, 2002). Several studies have tried to disentangle these different types of configural processing. In particular, the finding of key phenomena like the composite face effect (better recognition of the top half of an upright face when in composite with a congruent vs. and incongruent bottom half) and the part-whole effect (higher recognition performance of a feature when presented in the context of the whole face vs. presented in isolation) have highlighted the role that holistic processing and first-order relations (in the case of the composite effect) and holistic processing alone (in the case of the part-whole effect) play in face recognition (Murphy, Grey, & Cook, 2017; Goffaux & Rossion, 2006; Tanaka & Farah, 1993; Tanaka & Sengco, 1997). Other studies have directly manipulated face stimuli in order to disrupt first or second-order relations (e.g. scrambled faces, Mooney faces, Thatcherised faces) in order to study how face recognition performance would be affected. Importantly, inversion has been found to interfere with all types of configural processing for example by reducing the composite effect as well as the part-whole effect. Thus, inversion stands as a robust manipulation used to study the nature of face recognition skills (for a review see Maurer et al., 2002).

Perhaps the strongest evidence for the expertise account comes from the work conducted on perceptual expertise and the inversion effect after pre-exposure to novel categories of objects named Greebles (Gauthier & Tarr, 1997) and the inversion effect for dot patterns that shared a configuration (Tanaka and Farah, 1991). Moreover, McLaren (1997) first and then Civile, Zhao et al (2014) using an *old/new recognition task* as that often used in the face inversion effect literature (Yin, 1969; Diamond & Carey, 1986), provided the first evidence of a robust inversion effect for non mono-orientated prototype-defined categories of checkerboards (i.e. shared a configuration) that was predicted based on a specific model of perceptual learning, the MKM model (McLaren, Kaye & Mackintosh, 1989; McLaren & Mackintosh, 2000). Taken all together, Gauthier and Tarr (1997), McLaren (1997), and

Civile, Zhao et al (2014)'s work provide support for the Diamond and Carey (1986)'s expertise account of face recognition. And, they have also served as a basis for further investigations of face and object recognition using Electroencephalogram (EEG) derived event-related potentials (ERPs).

The first ERPs studies that looked at face recognition reported a larger positive potential at the vertex (named VPP) following the presentation of a face stimulus compared to other visual objects. Importantly, the VPP also presented a negative counterpart component at occipitotemporal sites, suggesting sites of origin in areas of the temporal cortex (Bötzel & Grüsser, 1989; Jeffreys, Tukmachi, Rockley, 1992). The VPP was particularly emphasized because few electrodes were usually placed on posterior regions and the reference was often located in the vicinity (e.g. mastoid) of the electrode sites picking up the occipitotemporal activity. As a result, the amplitude of the occipitotemporal negativity was attenuated and the VPP increased (Joyce & Rossion, 2005). In subsequent studies, the use of a different reference (e.g. common average) to analyze the ERPs, and the availability of EEG systems with a larger number of electrodes favored the investigation of the occipitotemporal negative counterpart of the VPP, later on named the N170 peak component (Rossion & Corentin, 2011). The key advantage of focusing on the N170 is that the electrodes recording on the scalp are closer to the neural generators of the component (Rossion & Corentin, 2011; Joyce & Rossion, 2005). Hence, the N170 quickly become the most studied "face-sensitivity" component and reflects a negative-polarity deflection (peak) maximal between 130 to 220 ms (although the onset time has rarely been measured precisely) after the onset of a face stimulus (Rossion & Corentin, 2011). The first systematic evidence on the N170 in response to faces was given by Bentin et al (1996) showing a larger N170 amplitude for images of human faces compared to images of animal faces, human hands, and objects (e.g. houses, flowers, and tools: see also Carmel & Bentin, 2002). Several studies have shown how inverted faces elicited a delayed (in terms of latency) N170 component compared to upright faces, which is also sometimes reflected by an enhancement of the N170 amplitudes (Anaki, Zion-Golumbic, & Bentin, 2007; Eimer, 2000; Jacques & Rossion, 2007; Marzi & Viggiano, 2007; Righart & de Gelder, 2006). The delayed N170 in response to inverted faces has often been interpreted as a result of configural processing disruption, and studies using sets of manipulated faces (e.g. scrambled, Thatcherised) have reported a clear reduction of the inversion effect (i.e. less delay for inverted faces) for these stimuli (Civile, Elechlepp et al., 2018; Civile et al., 2020). However, the fact that often the N170 amplitude has been found to be larger for inverted compared to upright faces is still puzzling and the subject of considerable debate in the literature. If inversion manipulation disrupts configural processing, the N170 that is supposed to be sensitive to this type of processing should be reduced rather than increased in response to inverted face stimuli. An explanation based on Itier, Alain, Sedore and McIntosh (2007) 's work is that the N170 amplitude is increased by additional recruitment of eye-specific cells by inverted faces. Hence, the disruption of configural information induced by inversion would result in extra salience of the eyes as features which would then lead to an increased N170. An alternative explanation was offered by Rossion et al (2000), who argued that both upright and inverted faces activate some face-specific neurons, however, inverted faces would also activate object-sensitive neurons, increasing the amplitude of response. Although a comprehensive and generally accepted explanation for the effects of inversion on the N170 has not yet been developed, the presence of such a delayed and sometimes larger N170 in response to inverted faces indicates that this component is linked to face processing (for a recent review see Eimer, 2011).

In a similar way to the literature on the behavioural face inversion effect, authors have investigated how the N170 component is modulated by perceptual expertise for prototype-defined categories of novel stimuli. Rossion et al (2002), showed that ERPs recorded before the training phase revealed a larger inversion effect on the N170 component for faces compared to that found for Greebles. Critically, that was not the case for the results after the training phase with the categories of Greebles where the inversion effect on the N170 was comparable for the two stimulus's types. In a similar vein, Busey and Vanderkolk (2005) investigated the inversion effect on the N170 in response to images of faces and fingerprints. The authors showed that fingerprint experts exhibited a delayed (but not larger) N170 for inverted fingerprints similar to that exhibited with inverted faces.

Furthermore, Civile, Zhao et al (2014) extended the old/new recognition task for checkerboards to ERPs. Participants were first trained to categorise chequerboard exemplars (the pre-exposure phase) generated from two prototype-defined categories. Checkerboard stimuli were chosen because they have the advantage that experience with them can be fully controlled (and they are not mono-orientated). Following this, participants were asked to memorise a number of new checkerboards drawn from either the 'now familiar' categories or a novel category not seen during the pre-exposure phase, half of which were presented upright and half inverted. Participants were then tested with an old/new recognition task were all the stimuli seen in the study phase were presented again intermixed with new stimuli split by the four stimulus conditions (familiar category upright/inverted, novel category upright/inverted). The behavioural results showed a robust inversion effect for exemplars drawn from a familiar category, that was absent for exemplars drawn from a novel category, Critically, the electrophysiological results recorded at PO8 channel revealed a larger inversion effect on the N170 (delayed and enlarged peak for inverted vs upright checkerboards) for exemplars drawn from a familiar category vs those drawn from a novel category. The effects on the N170 were found to be more robust during the study phase. This is in line with Civile, Elchlepp et al (2018) and Civile et al (2020)'s studies that revealed a more robust difference during the study phase between the inversion effect found on the

N170 for normal faces vs that found scrambled or Thatcherised faces. The overall findings from Civile, Zhao et al (2014) were explained by appeal to the MKM theory of perceptual learning, which suggests that during categorisation (the pre-exposure phase), participants are exposed to the features that the category exemplars possess. The features common to category exemplars rapidly lose their salience because they are presented on almost every trial and reliably predict one another, and so become slow to form new associations. This produces perceptual learning because the features unique to each exemplar still have high salience due to less exposure and lower predictability. Thus, it is easier for the participants to discriminate between exemplars in an upright orientation (the one they've been exposed to) because the salience of the common features is now low, whereas that of the unique features is still high.

In recent years, first Civile, Verbruggen et al (2016), and then Civile, McLaren, and McLaren (2018), Civile, Obhi, Mclaren (2019) and Civile et al (2020) strengthened the analogy between the inversion effect for checkerboards (Civile, Zhao et al., 2014) and the traditional inversion effect for faces, through demonstrating that they both share at least some aspects of the same causal mechanism. Using a particular transcranial Direct Current Stimulation (tDCS) paradigm, the authors were able to influence perceptual learning and affect the robust inversion effect that otherwise would have been obtained for checkerboards and face stimuli. Ambrus et al (2011) showed that anodal tDCS delivered over the left dorsolateral prefrontal cortex (DLPFC) at Fp3 site can eliminate the prototype distortion effect by affecting participants' ability to identify prototype and low distortion pattern exemplars as category members compared to sham. The specific region was selected based on a previous fMRI study showing increased brain activation during a category learning task involving two sets of prototype-defined categories of coloured checkerboards. The left

DLPFC was found to be highly activated in participants who showed a high level of categorization performance (Seger et al., 2000).

Civile, Verbruggen et al (2016) extended the tDCS montage adopted by Ambrus et al (2011) (see also McLaren et al., 2016 and Kincses et al, 2013 for examples of the same montage on categorization learning tasks) to the same old/new recognition task for prototype-defined categories of checkerboards developed by Civile, Zhao et al (2014). Anodal tDCS delivered over the DLPFC at Fp3 site for 10 mins at an intensity of 1.5mA reduced the inversion effect (compared to sham) found for checkerboards by reducing performance for upright checkerboards taken from a familiar category (Civile, Verbruggen et al., 2016). Critically, the same tDCS paradigm was also able to reduce (compared to sham) the face inversion effect by affecting recognition performance for upright faces (Civile et al., 2018; Civile et al., 2019; Civile et al., 2020). Importantly, an *active control* study Civile et al (2018, Experiment 3) showed that applying the same tDCS anodal stimulation at a different site on the scalp did not result in any modulation of the face inversion effect compared to the sham group. These results show that relatively brief tDCS stimulation is able to significantly affect one of the most robust empirical phenomena in the face recognition literature, and that, by analogy with the result obtained with chequerboards, this is attributable to an effect on perceptual learning.

Only two published studies have looked at the effects of tDCS on face recognition linked to the N170 component. Lafontaine, Theoret, Gosselin, and Lippe (2013) investigated the effects of tDCS delivered over the DLPFC on the N170 in response to upright faces. Using a single-blind within-subjects procedure, participants first received the tDCS stimulation followed by an encoding task/study phase where they observed a set of upright faces shown one at a time and repeated 15 times each. Following this, the participants performaned an old/new recognition task. In accordance with the 10/20 EEG placement system, in one condition the anodal tDCS electrode was located at the F3 site (left) while the cathodal electrode was located at F4 (right). In another condition the two electrodes were swapped. In the sham condition, electrodes were applied bi-frontally and stimulation was maintained for the first 30 seconds only. The behavioural results showed no effects of the tDCS. Importantly, during the encoding/study phase the results from the TP8 channel revelaed an increased N170 peak amplitude when the anodal stimulation was delivered at F3 (left) compared to the condition when anodal tDCS electrode was placed at F4 (right). The differences between sham and the active tDCS conditions were not significant. No significant effects were found on the N170 latencies. These results provide the first evidence in support of the hypothesis that tDCS stimulation delivered over the DLPFC can modulate the N170 over occipito-temporal sites in response to faces. Yang et al (2014, Experiment 1) investigated the effects of tDCS (right anodal left cathodal, right cathodal left anodal, sham) this time delivered at occipital-temporal sites (P7/P8), on the N170 during an orientation judgment task. After the the tDCS was administered, participants were presented with a set of faces and asked to judge as quickly as possible whether the face was upright or inverted. Performance in terms of recognition of the face was not the aim of the experiment nor was the inversion effect (responses to upright and inverted faces were analysed separately). The results showed no effects of tDCS on the behavioural results (both accuracy and RTs). The results from the N170 recorded at P8/P08 revealed a significantly reduced amplitude for upright faces in both active tDCS conditions compared to sham. No difference was found between the two active conditions. A similar result was found for inverted faces, where the N170 amplitude was reduced in the two active tDCS conditions compared to sham. However, this difference was only marginally significant. No differences were recorded on the N170 latencies. Taken all together, these two studies would suggest that tDCS delivered at DLPFC would have quite a different impact on the N170 peak amplitude compared to that at occipital sites.

In the present study, we extended the tDCS procedure adopted by Civile, Verbruggen et al (2016), Civile et al (2018), Civile et al (2019) and Civile et al (2020) to the face inversion effect on the N170 ERP component. We adopted a double-blind, between-subjects (so that our naïve participants cannot tell the difference between active and sham stimulation) experimental design. To our knowledge, this is the first study that attempts to examine tDCS-induced behavioural effects on the face inversion effect by looking at the N170 component. To do so we combined tDCS and EEG online (tDCS stimulation, EEG recordings, and behavioural task started all at the same time). We note that this created some technical problems in Experiment 1a, where the tDCS and EEG systems used were not completely compatible, and hence the EEG results from the study phase of that experiment were not analysable. However, because the tDCS stimulation ended with the study phase, we were able to analyse the EEG data from the recognition task (in addition to the behavioural data). Following this, we conducted Experiment 1b, which replicated the exact same exprimental procedure as Experiment 1a, but this time used a compatible tDCS/EEG system that allowed us to analyse the EEG data from both study phase and the recognition phase.

The use of the inversion effect in the current studies is particularly important. We expected our overall behavioural results to show the reduction in the face inversion effect contingent on our tDCS procedure in line with previous studies. Secondly, we expected that a reduction of the behavioural inversion effect would be accompanied by a reduction of the inversion effect on the N170 latency. If confirmed, this would suggest that the tDCS procedure reduces the inversion effect for normal faces by affecting expertise at exploiting the configural information contained within a face a similar analysis as is applied to direct manipulations of the face stimuli (e.g. scrambling or Thatcherising a set of faces). Finally, although not investigated directly, based on previous ERP studies that have found the effects on the N170 to be more robust during the study phase, in the current study as well we expected to record stronger effects during the study phase. Thus, we initially kept the EEG analysis for the study phase and recogntion phases separate.

EXPERIMENT 1A

Method

Subjects

In total, 48 naïve (right-handed) subjects (18 male, 30 Female; Mean age = 21.3 years, age range= 18-27, *SD*= 2.25) took part in the study. Subjects were randomly assigned to either sham or anodal tDCS groups (24 in each group). All the subjects were students from the University of Exeter and were selected according to the safety screening criteria approved by the Research Ethics Committee at the University of Exeter. The sample size was determined from earlier studies that used the same tDCS procedure, EEG paradigm, face stimuli, and counterbalancing (Civile et al., 2018, Civile, Elchlepp et al., 2018; Civile et al., 2019; Civile et al., 2020). Additionally, we conducted a post-hoc power analysis, using G*Power software (Faul et al., 2007), based on the effect size recorded from the overall 2 x 2 interaction in the behavioural results. This analysis revealed a statistical power of 0.66 (Effect size f = 0.18, 2 groups, 2 measurements). Thus, in Experiments 1b we increased the sample size.

Materials

The study used a set of 256 face images standardized to grayscale on a black background previously used in Civile et al (2018), Civile et al (2019) and Civile et al (2020). All face images were cropped removing distracting features such as hairline and adjusted for extreme differences in image luminance (see Figure 1). The stimuli, whose dimensions were 5.63 cm x 7.84 cm, were presented at resolution of 1280 x 960 pixels. The experiment was run using E-prime software installed on a PC computer.

The Behavioural Task

The experiment consisted of a *study phase* and an *old/new recognition phase* (Figure 1, Panel b) just like the procedure used in previous studies (Civile et al., 2014; Civile, McLaren & McLaren, 2016; Civile et al., 2018; Civile et al., 2019; Civile, McLaren, & McLaren, 2011). Once subjects gave their consent, the instructions for the *study phase* were presented on the screen. Subjects were instructed to try to memorize the faces presented on the screen. The trial started with a fixation cross (500ms) in the centre of the screen, immediately followed by a blank screen (500ms), and then by a facial stimulus (3000ms). Then the fixation cross and the black screen were repeated, and another face presented, until all stimuli had been presented. Overall, 128 face stimuli were presented, 64 in their upright orientation and 64 were presented inverted. After all the 128 face stimuli had been presented, the program displayed another set of instructions, explaining the recognition task. Now, subjects were asked to press the ‘z’ key if they recognized the face stimulus as having been shown in the *study phase* on any given trial, or press ‘m’ if they did not (the keys were counterbalanced across participant groups). All the stimuli previously seen in the *study phase* were presented again, these are the “old” stimuli, intermixed with 128 “new” face images split by the two conditions (upright and inverted). All the faces were presented one at a time in a random order. The trial structure was as for the *study phase* however this time the stimuli were presented for a longer period (up to 4000ms) until either a response was made or a timeout.

The tDCS Paradigm

In the present study 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 area of stimulation. We adopted the same tDCS montage used in Civile et al (2016), Civile et al (2018, Experiment 1 & 2), Civile et al (2019) and Civile et al (2020) (Figure 1, Panel a). Hence, one of the electrodes (anode) was placed over the target stimulation area (Fp3) and the other (cathode) on the forehead over the reference area (right eyebrow). The study was conducted using 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 “normal” (i.e. anodal) and “sham” stimulation. In the anodal condition, a direct current stimulation of 1.5mA was delivered continuously for 10 mins (5 s fade-in and 5 s fade-out) starting as soon as the subjects began the behavioral task and continuing throughout the study phase. In the sham group, 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 (3 ms) was delivered every 550 ms (0.1mA over 15 ms) for the remainder of the 10 mins to check impedance levels. Subjects were randomly assigned to one of the tDCS groups (Sham or Anodal). For every subject the stimulation started at the beginning of the *study phase* and ended before the *old/new recognition* task started.

Given the novelty inherent in combining tDCS and EEG techniques, especially with using two separate pieces of equipment, it is worth noting some of the practical challenges faced during the implementation of the study. Specifically, when we first tested the combination of these techniques, we realised that the tDCS stimulation (both sham and anodal) induced strong artefacts on the EEG data. Thus, we made sure that the tDCS stimulation ended by the end of the study phase before we started recording the EEG for the recognition phase. Hence, our analysis of the EEG data will be entirely for the recognition phase. We addressed this problem later on in the Experiment 1b when we adopted different apparatus (i.e. Starstim System) designed to combine tDCS and EEG.

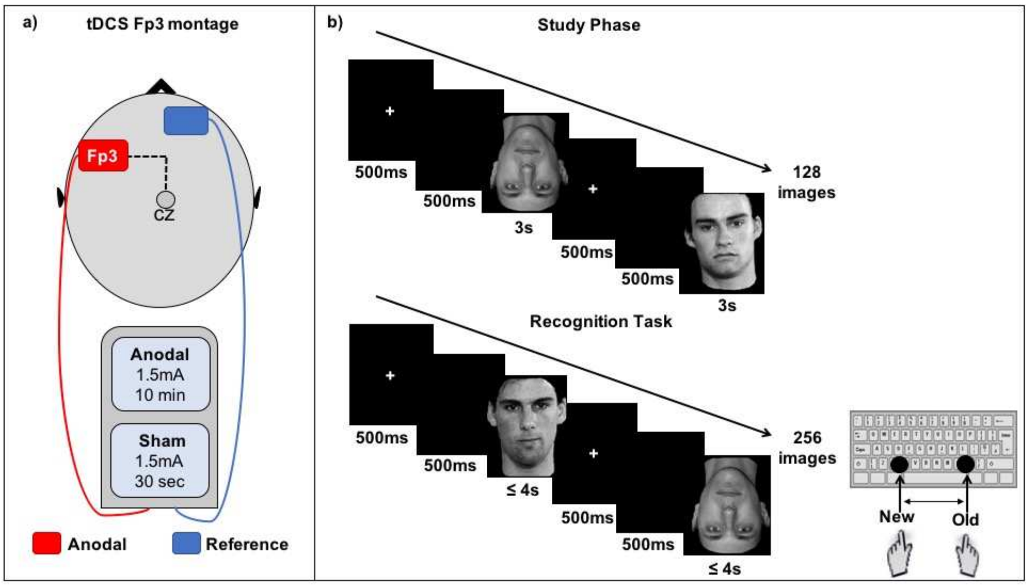

Figure 1. <u>Panel a</u> shows the tDCS montage adopted in Experiment 1a and 1b. This was the same montage used in Civile et al (2016), Civile et al (2018), Civile et al (2019) and Civile et al (2020). **<u>Panel b</u>** illustrates the *old/new recognition* task used in the two experiments here reported.

EEG Recordings

The EEG was sampled at 1000 Hz, with a band-pass of 0.016-100 Hz, the reference at Cz and the ground at Fz using 32 Ag/AgCl active electrodes and BrainAmp amplifiers. The electrodes were placed on the scalp in an extended 10-20 configuration plus one on each earlobe (references during online recording). Their impedances were kept below 10 kΩ.

EEG Data Processing and Analysis

As mentioned above in the *tDCS Paradigm* section the ERP analysis was limited to the recognition phase. Data processing was performed in BrainVision Analyzer. The data was first filtered offline using a Butterworth Zero Phase filter with a low cutoff of 0.5 Hz and a high cutoff of 30 Hz, each with a 24 dB/oct slope. Individual channels were manually inspected and removed from further analysis where physical interference from a tDCS electrode was noted during set-up, or where data otherwise showed signs of significant artefacts throughout. Electrodes were re-referenced offline to Cz. This was due to differences in discarded channels for each participant, therefore preventing a common average being created that included the same channels for all participants. To correct for ocular movements and other such artefacts an Independent Component Analysis (ICA, Bell & Sejnowski, 1995) was applied for each participant. Resulting components were visually scrutinized and the data was back-transformed to exclude components primarily containing ocular artefacts (eye blinks and eye movements). The EEG data was then segmented into epochs starting at 100ms pre-stimulus and ended at 500ms post-stimulus. Baseline correction was applied (using the mean voltage of the 100ms pre-stimulus) and resulting segments were manually inspected for any residual ocular or other artefacts. Finally, segments were averaged with respect to face orientation condition (upright and inverted). The ERP N170 latency and amplitude analyses were restricted to electrode PO8, (over the right temporal hemisphere) which often in the literature has shown bigger effects on the N170 in response to face stimuli (Rossion & Jacques, 2008, Prieto, Cahare, Henson, Rossion, 2011, Navajas, Ahmadi, Quian Quiroga, 2013, Civile, Elchlepp et al., 2018; Civile et al., 2012). We also chose this electrode because a larger effect on the P08 was recorded in Civile, Zhao et al (2014, Experiment 4)'s study on perceptual learning and the inversion effect on the N170 in response to prototype-defined familiar checkerboards. A semi-automatic procedure was used for peak selection for the N170 defined as the most negative point between 140 and 220ms. Information concerning peak amplitude and peak latency was then extracted. The effects of the tDCS stimulation on the inversion effect on the ERPs waveform were therefore tested via a mixed measures 2 x 2 ANOVA for both N170 amplitudes and latencies.

Results

Behavioural Data Analysis

Following Civile et al (2018), Civile et al (2019) and Civile et al (2020) the data from all the participants were used in the signal detection d' sensitivity analysis of the recognition task (seen and not seen stimuli for each stimulus type) where a *d'* = of 0.00 indicates chance-level performance (Stanislaw & Todorov, 1999). We assessed performance against chance to show that both upright and inverted face stimuli in both the tDCS sham and anodal groups were recognized significantly above chance (for Sham Inverted, Sham Upright and Anodal Upright we found $p < .001$ for this analysis, for Anodal Inverted we found $p = .016$). 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. We also analyzed the reaction times (RTs) data to check for any speed-accuracy trade-off. We do not report this analysis here because it does not add anything to the interpretation of our results. For completeness, we give mean RTs for each of the stimulus' conditions: Sham Upright = 1240 ms; Sham Inverted = 1277 ms; Anodal Upright = 1263 ms; Anodal Inverted = 1267 ms.

D-Prime Analysis

We computed a 2 x 2 mixed model design using, as a within-subjects factor, *Face Orientation* (upright or inverted), and the between-subjects factor *tDCS Stimulation* (sham or anodal). Based on previous studies (Civile et al., 2018; Civile et al., 2019; Civile et al., 2020) we expected the inversion effect for the anodal group to be smaller than that in the sham group. Analysis of Variance (ANOVA) revealed that numerically this was case but this time the interaction was not statistically significant, $F(1, 46) = .947$, $p = .33$, $\eta^2_p = .02$. There was a significant main effect of *Orientation* $F(1, 46) = 43.95$, $p < .001$, $\eta^2_p = .48$, which confirmed that upright faces were better responded to than inverted ones. A significant main effect of tDCS was found $F(1, 46) = 5.40$, $p = .025$, $\eta^2_p = .10$. Paired *t* test analyses were conducted to compare performance on upright and inverted face stimuli (the inversion effect) in each tDCS group (sham, anodal). Based on previous studies that used the same stimuli and tDCS paradigm (Civile et al., 2018; Civile et al., 2019; Civile et al., 2020) our primary measure was the face inversion effect given by comparing performance on upright and inverted faces in each tDCS group. We also directly compared the performance for upright faces in the sham vs tDCS group. This is particularly appropriate because the same stimulus sets are rotated across participants in a counterbalanced manner; so that each upright face seen in the anodal group for a given participant will equally often serve as an upright face for the participants in the sham group. A significant inversion effect was found in the sham group (M=.495, SE=.10), $t(23) = 4.97$, $p < .001$, $\eta^2_p = .38$, and a numerically reduced inversion effect was found in the tDCS anodal group (M=.368, SE=.07), $t(23) = 4.62$, $p < .001$, $\eta^2_p = .25$ (see Figure 2). Recognition for upright face stimuli in the anodal group was lower compared to that in the sham group, $t(46) = 2.05$, $p = .051$, $\eta^2_p = .19$. We also found a trend towards performance for inverted faces being reduced in the anodal relative to the sham group, $t(46) = 1.81$, $p = .083$, $\eta^2_p = .16$.

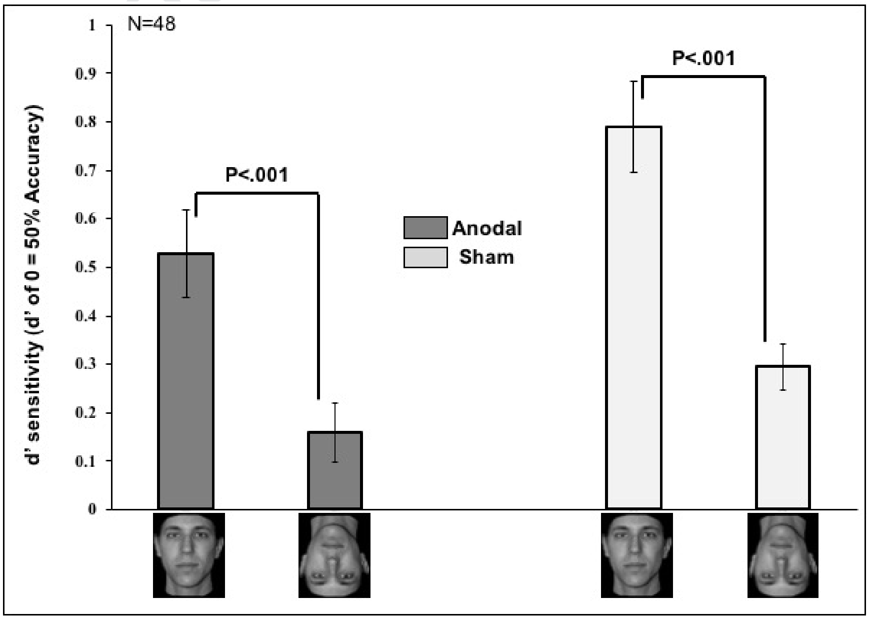

Figure 2. Results for the old/new recognition task. The *x*-axis shows the stimulus conditions. The *y*-axis shows sensitivity d' measure. Error bars represent s.e.m.

N170 ERP Results

In analyzing the N170 peak component we computed the same statistical analyses as for the behavioral data.

N170 Peak Latency Analysis

A 2 x 2 repeated measure ANOVA revealed a trend towards a significant interaction between Orientation and Stimulation for peak latency, $F(1,46) = 3.26$, p = .077, $\eta^2_p = .06$. A significant main effect of *Orientation* was found (greater latency for inverted stimuli), $F(1, 46) = 51.19$, $p < .001$, $\eta^2_p = .52$. No main effect of tDCS was found $F(1, 46) = .077$, $p = .78$, $\eta^2_p < .01$. A significant inversion effect (i.e. a delayed N170 peak for inverted vs upright faces) was found in the sham group (M=7.95ms, SE=1.28), $t(23) = 6.20$, $p < .001$, $\eta^2_p = .62$, and a numerically reduced inversion effect was found in the tDCS anodal group (M=4.70ms, SE=1.22), $t(23) = 3.86$, $p < .001$, $\eta^2_p = .39$ (Figure 3, Panel a & b). It is this reduction that is driving the interaction referred to earlier. No reliable difference was found between the N170 latencies for upright stimuli in the anodal and sham groups, $t(46) = .235$, $p = .815$, $\eta^2_p < .01$, and no significant difference was found between inverted faces in the anodal and sham groups, $t(46) = .903$, $p = .375$, $\eta^2_p = .04$.

N170 Peak Amplitude Analysis

A 2 x 2 ANOVA revealed a significant *Orientation* by *Stimulation* interaction for peak amplitude, $F(1,46) = 4.06$, p = .049, $\eta^2_p = .09$, and a main effect of *Orientation* (greater negative deflection for inverted stimuli), $F(1, 46) = 45.47$, $p < .001$, $\eta^2_p = .49$. No main effect of tDCS was found $F(1, 46) = .178$, $p = .67$, $\eta^2_p < .01$Contrary to what we found for N170 latencies, the inversion effect (greater deflection for inverted vs upright faces) was found to be larger in amplitude in the anodal group (M=3.32µV, SE=.63) $t(23) = 5.22$, $p < .001$, $\eta^2_p = .54$, compared to that found in the sham group (M=2.41µV, SE=.52) $t(23) = 4.32$, $p < .001$, $\eta^2_p = .44$ (Figure 3, Panel a & c). The interaction for the amplitude measure was thus opposite to that observed for latency. No reliable difference was found between the N170 amplitude for upright stimuli in the anodal vs sham group, $t(46) = .033$, $p = .975$, $\eta^2_p = .00$. Despite a numerically larger N170 for the inverted faces in the anodal vs sham group, there was no significant difference, $t(46) = .882$, $p = .386$, $\eta^2_p = .03$.

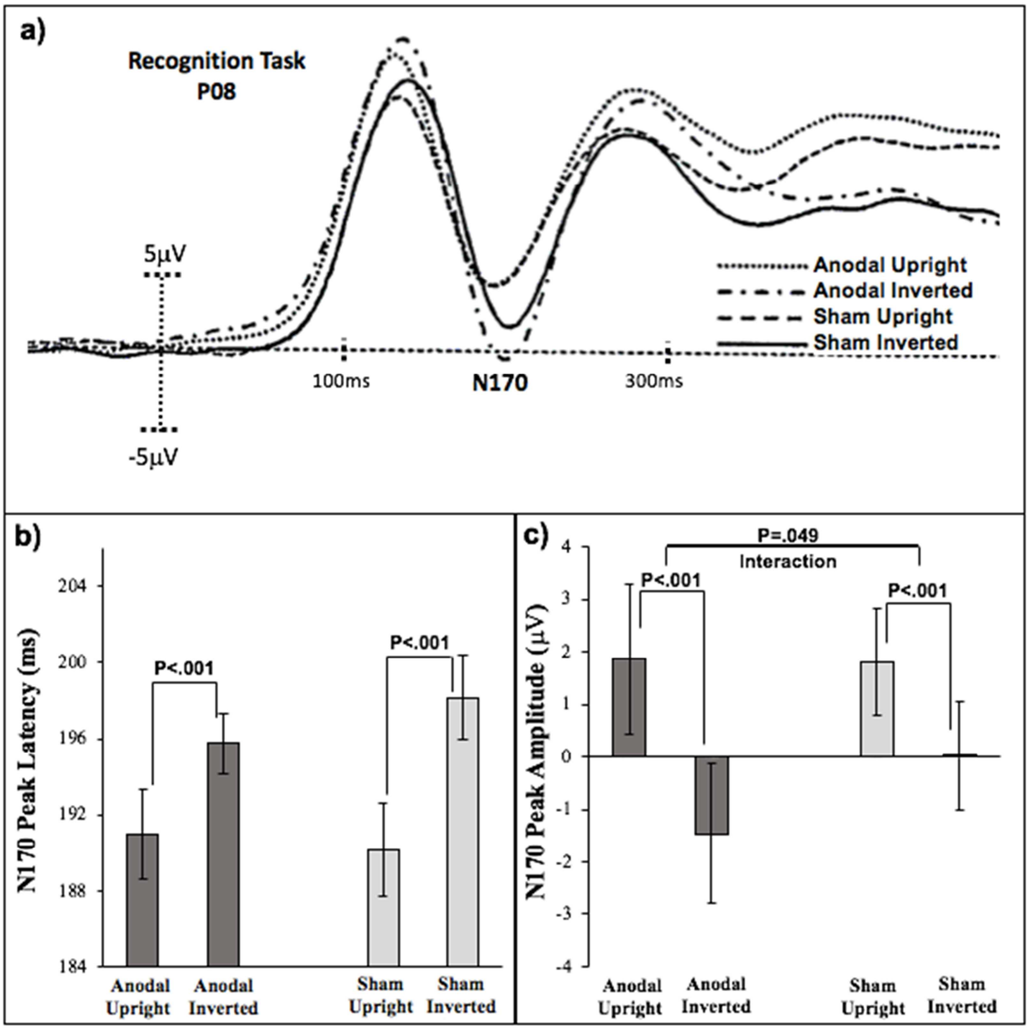

Figure 3. **Panel a**, Waveforms at electrode P08 for the four stimulus' conditions in the recognition phase. The X axis shows the elapsed time after a stimulus was presented. The Y axis gives the amplitudes (µV) of the ERPs in the recognition phase of Experiment 1a. **Panel b**, mean peak latencies (ms) for the N170 component in all stimulus' conditions. **Panel c**, mean peak amplitudes (µV) for the N170 component in all stimulus' conditions.

Before we discuss these results we now present the data from Experiment 1b, which complements and extends the findings of Experiment 1a, before considering both experiments in combination.

EXPERIMENT 1B

Method

Subjects

For Experiment 1b we aimed to increase the sample size (to give statistical power > .90). Overall, we recruited 64 naïve (right-handed) subjects (15 male, 49 Female; Mean age = 21.1 years, age range= 18-28, *SD*= 2.40). As for Experiment 1a, the subjects were randomly assigned to either sham or anodal tDCS groups (32 in each group). All the subjects were students from the University of Exeter and were selected according to the safety screening criteria approved by the Research Ethics Committee at the University of Exeter. A power analysis based on the effect size recorded from the overall 2 x 2 interaction in the behavioural study revealed a statistical power of 0.94 (Effect size *f* = 0.294, 2 groups, 2 measurements) this time.

Materials and Behavioural Task

Both materials and the behavioural task were exactly the same as for Experiment 1a.

The tDCS Paradigm

We adopted the same tDCS montage as that used in Experiment 1a. However, in Experiment 1b we used a different tDCS system (Starstim system) previously adopted by Civile et al (2019) and Civile et al (2020) which allowed us to concurrently record EEG. Hence, the stimulation was delivered by a battery driven, constant current stimulator (Neuroelectrics) via a pair of surface sponge electrodes (35 cm^2), soaked in a saline solution and applied to the scalp at the target areas of stimulation. The study was conducted using a double-blind procedure reliant on the Neuroelectrics double-blind mode. Just like in

Experiment 1a, we adopted a bilateral bipolar-non-balanced montage with one of the electrodes (anode/target) placed at Fp3 and the reference was placed on the forehead (above the right eyebrow).

EEG Recordings

EEG was recorded with the Enobio system (Neuroelectrics) which is a wireless electrophysiology sensor system. The Necbox (the control unit) connects through Wi-Fi to the Neuroelectrics Instrument Controller (NIC) software running on a computer. The EEG data is streamed via Wi-Fi and was sampled at 500 SPS with a bandwidth of 0 to 125 Hz (DC coupled). The Driven Right Leg (DRL) and the Common Mode Sense (CMS) connections corresponded to the electrical reference, or "ground", of the system. The CMS is the reference channel, compared to which all the EEG signals are measured. The DRL is responsible for bringing the potential of the subject as close as possible to the "zero" of the electrical system. Specifically, in the Enobio 20-channel (10-20 configuration) here used the CMS/DRL electrode is represented by the EarClip, an additional dual electrode system applied to the earlobe through conductive gel. In NIC (we used the latest version n.2) the quality of the EEG signals is assessed via the quality index (QI) which is computed every 2 seconds and is dependent on the following parameters: i) Line Noise power (μV2) of the signal in the standard line noise frequency band (50±1 Hz); ii) Main noise signal power of the standard EEG band (1–40Hz); iii) Offset, mean value of the waveform; iv) Drift, which is measured but not included in the QI computation because it has a high inter-subject variability. Before starting the recording (and the tDCS stimulation), we made sure the QI for each channel was indicated as “good” (i.e. in orange/green colour).

EEG Data Processing and Analysis

As in Civile, Elchlepp et al (2018), the EEG data processing was performed in MATLAB with the open-source EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-

Calderon & Luck, 2014) toolboxes. Hence, we adopted the same processing and analysis procedure as for Civile, Elchlepp et al (2018)'s study (in Experiment 1a, we were not able to do so due to the problems encountered in combining the tDCS and the EEG equipment). The data were filtered off-line using a noncausal Butterworth bandpass filter (half-amplitude cutoffs at 0.1 and 20 Hz, 24 dB/octave roll-off). All scalp electrodes were referenced off-line to a common average reference. This was used in line with previous studies in the field specifically investigating the N170 for faces (e.g. Towler, Parketny, & Eimer, 2016; Feuerriegel, Churches & Keage, 2015; Civile, Elchleep et al., 2018), and for faces vs objects (e.g. Greebles; Rossion et al., 2002; cars, Goffaux, Gauthier, & Rossion, 2003). Conspicuously bad parts of the EEG recording were identified and removed using EEGLab's *pop_rejcont* function (threshold 12, all other settings default). To correct for blink artefacts, independent component analysis (ICA) was applied to the continuous data after the deletion of sections containing extreme values (Jung et al., 2000). Remaining artefacts exceeding ±100 mV in amplitude or containing a change of over 100 mV in a period of 50 ms were rejected (in ERPLAB this function is named Simple Threshold Voltage, Luck, 2014). Artefact-free data were then segmented into epochs ranging from 250 ms before to 800 ms after stimulus onset for all conditions (Zion-Golumbic & Bentin, 2007).

N170 Analysis

ERPs were created by averaging the segmented trials (and baseline corrected) according to the four stimulus' conditions in each phase of the experiment (study and recognition). The absolute peak of the N170 was determined using the ERPLAB Measurement Tool based on the option to select the most negative peaks between 140 and 220 ms. Subsequent visual scrutiny was applied to ensure that the values represented real peaks rather than end points of the epoch (Zion-Golumbic & Bentin, 2007, Civile, Elchlepp et al., 2018). As for Experiment 1a, N170 latency and amplitude analyses were restricted to electrode PO8. Hence, the effects of the tDCS stimulation on the inversion effect on the ERPs waveform were therefore tested via a mixed measures 2 x 2 ANOVA for both N170 amplitudes and latencies. Using the procedure outlined by Dienes (2011) we also conducted the Bayes Factor (BF) analyses for the 2 x 2 interaction from both N170 latency and amplitude results recorded in Experiment 1b (study phase, and recognition phase) using as the prior the difference between the inversion effect score in the sham and in the anodal group found for recognition phase N170 latency and amplitude results in Experiment 1a.

Results

Behavioural Data Analysis

As for Experiment 1a the data from all the participants were used in the signal detection d' sensitivity analysis of the recognition task. We assessed performance against chance for upright and inverted face stimuli in both the tDCS sham and anodal groups (for Anodal Inverted, Anodal Upright and Sham Upright we found $p < .001$ for this analysis, for Sham Inverted we found $p = .10$). 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. We also analyzed the reaction times (RTs) data to check for any speed-accuracy trade-off. We do not report this analysis here because it does not add anything to the interpretation of our results. For completeness, we give mean RTs for each of the stimulus' conditions: Sham Upright = 1171 ms; Sham Inverted = 1200 ms; Anodal Upright = 1200 ms; Anodal Inverted = 1247 ms.

D-Prime Analysis

We computed a 2 x 2 mixed model design using, as a within-subjects factor, *Face Orientation* (upright or inverted), and the between-subjects factor *tDCS Stimulation* (sham or anodal which revealed a significant interaction, $F(1, 62) = 5.85$, $p = .018$, $\eta^2_p = .08$. There was a significant main effect of *Orientation* $F(1, 62) = 27.93$, $p < .001$, $\eta^2_p = .31$, which confirmed that upright faces were better responded to than inverted ones. No main effect of tDCS was found $F(1, 62) = .001$, $p = .98$, $\eta^2_p < .01$. Paired *t* test analyses were conducted which revealed a significant inversion effect in the sham group (M=.402, SE=.05), $t(31) = 7.29$, $p < .001$, $\eta^2_p = .63$, and a non-significant inversion effect in the anodal group (M=.150, SE=.08), $t(31) = 1.68$, $p = .10$, $\eta^2_p = .08$ (Figure 4). Recognition for upright face stimuli in the anodal group was lower (numerically) compared to that in the sham group, but not significantly so, $t(62) = 1.06$, $p = .30$, $\eta^2_p = .03$. Performance for inverted faces was this time numerically higher in the anodal group relative to the sham group, $t(62) = 1.37$, $p = .175$, $\eta^2_p = .05$.

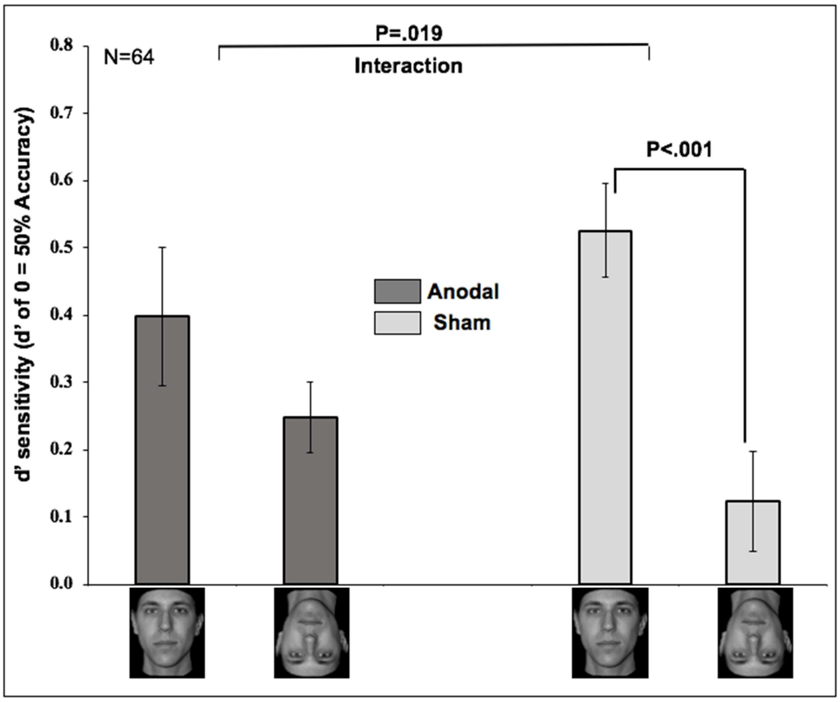

Figure 4. Results for the old/new recognition task in Experiment 1b. The *x*-axis shows the stimulus conditions. The *y*-axis shows sensitivity d' measure. Error bars represent s.e.m.

Behavioural Data Analyses for Experiment 1a and b combined

Because Experiment 1a and b used exactly the same behavioural task (including the same stimuli, counterbalance, and trial structure) we provide here the results for the two experiments combined together. We also provide a Bayes analysis for the difference between the inversion effect score in the sham and in the anodal groups (i.e. capturing the 2 x 2 interaction) in Experiment 1a and b combined, using as the *prior* the differences found in Civile et al (2018), Civile et al (2019) and Civile et al (2020) averaged together. And we also conducted a second BF analysis for upright faces in the sham group compared to that in the anodal group, using as prior the mean difference between sham upright faces minus anodal upright faces found in Civile et al (2018), Civile et al (2019) and Civile et al (2020) averaged together.

We computed a 2 x 2 x 2 mixed model design using, as a within-subjects factor, *Face Orientation* (upright or inverted), and the between-subjects factors *tDCS Stimulation* (sham or anodal) and *Experiment* (1a or 1b) which did not produce a significant three-way interaction (*Face Orientation* x *Stimulation* x *Experiment*), $F(1, 108) = .582$, $p = .447$, $\eta^2_p < .01$. There was a significant main effect of *Face Orientation* $F(1, 108) = 73.48$, $p < .001$, $\eta^2_p = .40$, which confirmed that upright faces were better recognised than inverted ones. No main effect of tDCS was found $F(1, 108) = 2.260$, $p = .13$, $\eta^2_p = .02$. Importantly, a significant interaction was found between *Face Orientation* and *tDCS Stimulation* $F(1, 108) = 5.281$, $p = .018$, $\eta^2_p = .04$, BF=74.67. Paired *t* test analyses were conducted which revealed a significant inversion effect in the sham group (M=.441, SE=.05), $t(55) = 7.97$, $p < .001$, $\eta^2_p = .53$, and a significant inversion effect in the anodal group (M=.243, SE=.06), $t(55) = 3.95$, $p < .001$, $\eta^2_p = .22$ (Figure 5). Critically, just like in Civile et al (2018), Civile et al (2019) and Civile et al (2020)'s studies, we find that recognition for upright face stimuli in the anodal group was significantly reduced compared to that in the sham group, $t(110) = 2.03$, $p = .046$, $\eta^2_p = .07$, BF=51.59. Performance for inverted faces on the anodal group was at about the same level as that relative to the sham group, $t(110) = .208$, $p = .836$, $\eta^2_p < .01$.

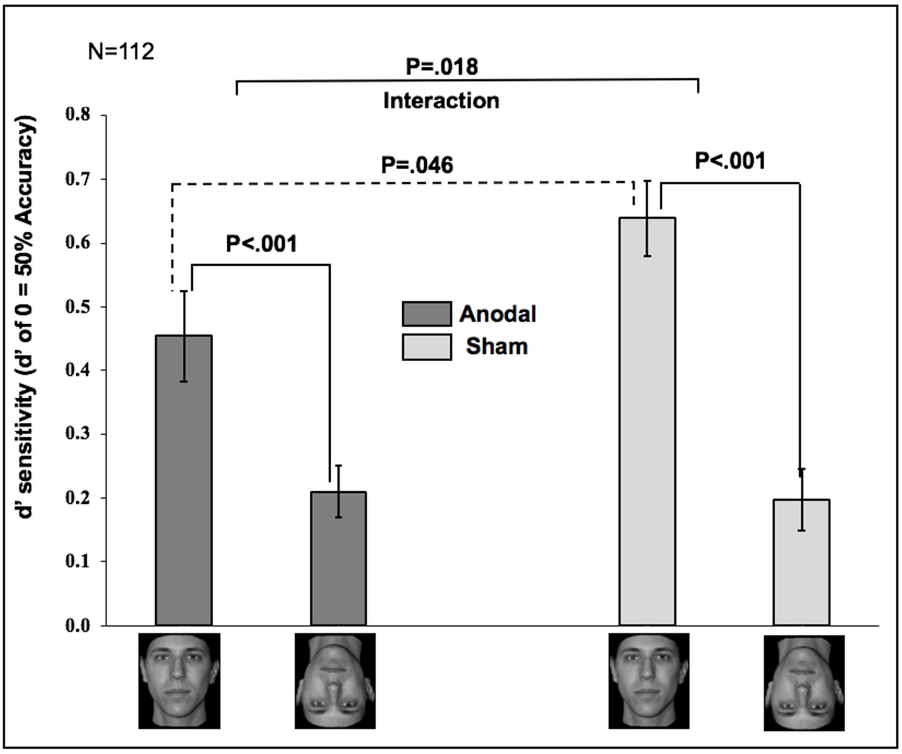

Figure 5. Results for the old/new recognition task in Experiment 1a and b combined. The *x*-axis shows the stimulus conditions. The *y*-axis shows sensitivity d' measure. Error bars represent s.e.m.

N170 ERP Results – Experiment 1B

Study Phase

N170 Peak Latency Analysis

A 2 x 2 repeated measure ANOVA revealed a significant interaction, $F(1,62) = 4.33$, p = .041, $\eta^2_p = .06$, BF=10.03. A significant main effect of *Orientation* was also found (latency greater for inverted), $F(1, 62) = 9.56$, $p = .003$, $\eta^2_p = .13$. No main effect of tDCS was found $F(1, 62) = .107$, $p = .74$, $\eta^2_p < .01$. A significant inversion effect was found in the sham group (M=12.15ms, SE=3.21), $t(31) = 3.78$, $p = .001$, $\eta^2_p = .31$, no significant inversion effect was found in the anodal group (M=2.37ms, SE=3.42), $t(31) = .692$, $p = .49$, $\eta^2_p = .01$ (Figure 6, Panel a & b). No reliable difference was found between the N170 latencies for upright stimuli in the anodal vs sham group, $t(62) = .168$, $p = .867$, $\eta^2_p < .01$, and no significant difference was found between inverted faces in the anodal vs sham group, $t(46) = .775$, $p = .441$, $\eta^2_p = .01$.

N170 Peak Amplitude Analysis

A 2 x 2 ANOVA revealed a significant *Orientation* by *Stimulation* interaction for peak amplitude, $F(1,62) = 5.43$, p = .023, $\eta^2_p = .08$, BF=108 and a main effect of *Orientation*, $F(1, 62) = 24.15$, $p < .001$, $\eta^2_p = .28$, with a greater negative deflection for inverted faces. No main effect of tDCS was found $F(1, 62) = .576$, $p = .45$, $\eta^2_p < .01$. As in Experiment 1a, the inversion effect was found to be larger in terms of amplitude difference in the anodal group (M=1.07μV, SE=.24) $t(31) = 4.39$, $p < .001$, $\eta^2_p = .38$, compared to that found in the sham group (M=.382, SE=.16) $t(31) = 2.28$, $p = .029$, $\eta^2_p = .14$ (Figure 5, Panel a & c). No difference was found between the N170 amplitudes for upright stimuli in the anodal vs sham group, $t(62) =.158$, $p = .875$, $\eta^2_p <.01$. Despite a numerically larger N170 for the inverted faces in the anodal compared to the sham group, no significant difference was found, $t(46) = 1.593$, $p = .21$, $\eta^2_p = .03$.

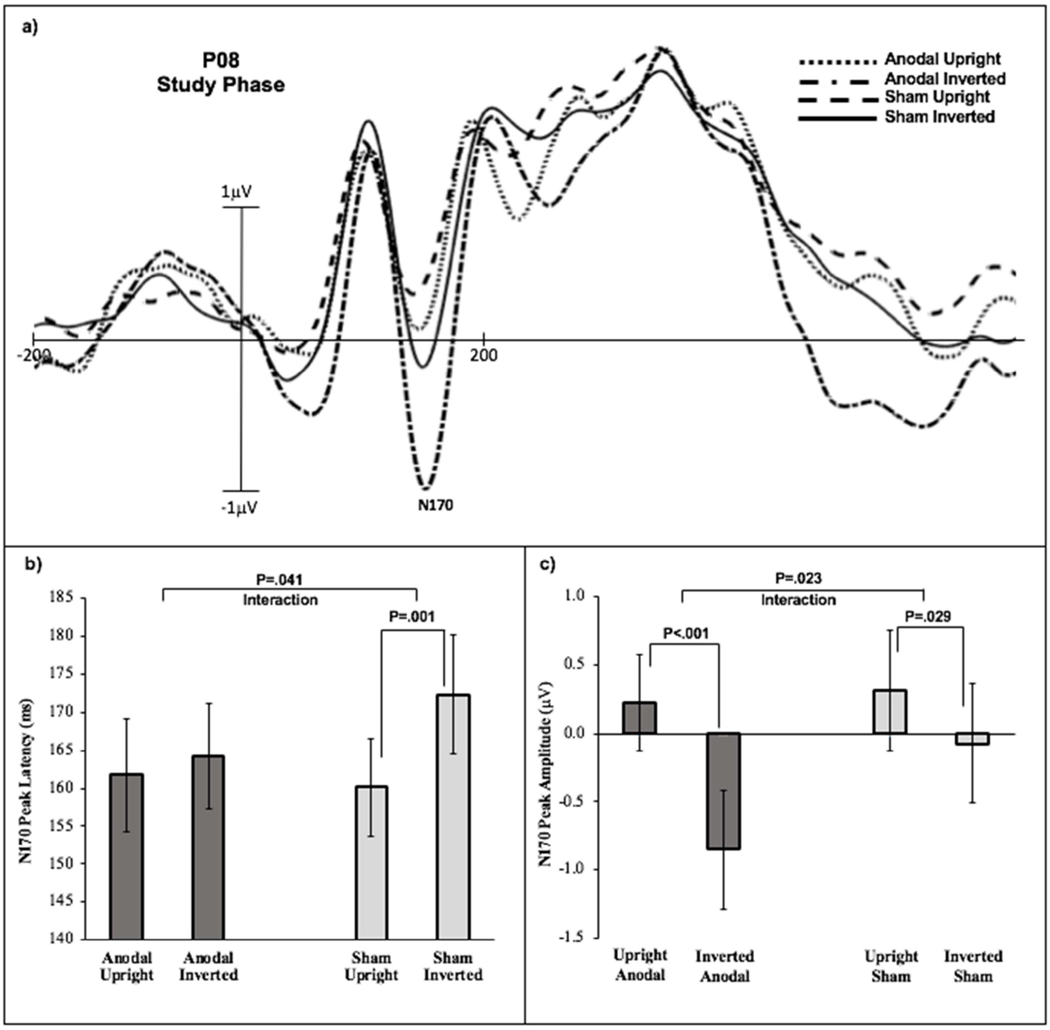

Figure 6. <u>Panel a</u>, Waveforms at electrode P08 for the four stimulus' conditions in the study phase. The X axis shows the elapsed time after a stimulus was presented. The Y axis gives the amplitudes (μV) of the ERPs in the study phase of Experiment 1b. **<u>Panel b</u>**, mean peak latencies (ms) for the N170 component in all stimulus' conditions. **<u>Panel c</u>**, mean peak amplitudes (μV) for the N170 component in all stimulus' conditions.

Recognition Phase

N170 Peak Latency Analysis

A 2 x 2 repeated measure ANOVA revealed a trend towards a significant interaction, $F(1,62) = 3.44$, p = .068, $\eta^2_p = .05$, BF=8.23, which was based on the inversion effect (mean difference in latencies for upright and inverted stimuli) being greater for the sham group. A significant main effect of *Orientation* was found (latency greater for inverted), $F(1, 62) =$

17.77, $p < .001$, $\eta^2_p = .22$. No main effect of tDCS was found $F(1, 62) = .143$, $p = .70$, $\eta^2_p < .01$. A significant inversion effect was found in the sham group (M=13.50ms, SE=2.81), $t(31) = 4.78$, $p < .001$, $\eta^2_p = .42$, no significant inversion effect was found in the anodal group (M=5.25ms, SE=3.43), $t(31) = 1.52$, $p = .13$, $\eta^2_p = .07$ (Figure 7, Panel a & b). No reliable difference was found between the N170 latencies for upright stimuli in the anodal vs sham group, $t(62) = .063$, $p = .95$, $\eta^2_p < .01$. No significant difference was found between inverted faces in the anodal vs sham group, $t(62) = .486$, $p = .63$, $\eta^2_p = .01$.

N170 Peak Amplitude Analysis

A 2 x 2 ANOVA revealed a trend towards a significant *Orientation* by *Stimulation* interaction for peak amplitude, $F(1, 62) = 3.26$, p = .076, $\eta^2_p = .05$, BF=10.87, and a significant main effect of *Orientation* (greater negative deflection for inverted stimuli), $F(1, 62) = 26.65$, $p < .001$, $\eta^2_p = .30$. No main effect of tDCS was found $F(1, 62) = .064$, $p = .78$, $\eta^2_p < .01$.The inversion effect was found to be numerically larger in terms of the amplitude difference in the anodal group (M=.685µV, SE=.11) $t(31) = 6.06$, $p < .001$, $\eta^2_p = .53$, compared to that found in the sham group (M=.330µV, SE=.16) $t(31) = 2.06$, $p = .048$, $\eta^2_p = .12$ (Figure 6, Panel a & c). No difference was found between the N170 amplitude for upright stimuli in the anodal vs sham group, $t(62) =.190$, $p = .85$, $\eta^2_p <.01$. Despite a numerically larger N170 for the inverted faces in the anodal vs sham group, no significant difference was found, $t(62) = .808$, $p = .42$, $\eta^2_p = .01$.

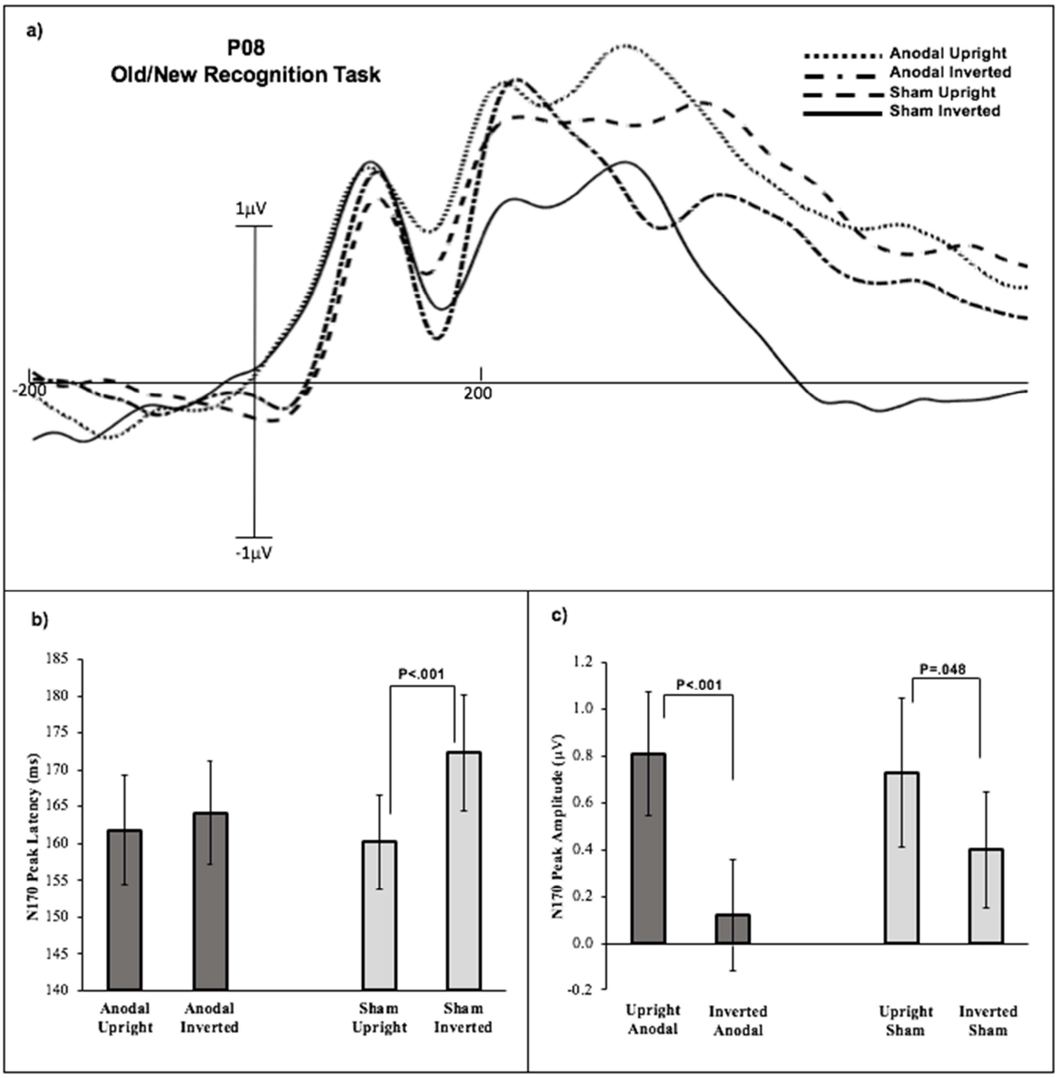

Figure 7. <u>Panel a</u>, Waveforms at electrode P08 for the four stimulus' conditions in the recognition phase. The X axis shows the elapsed time after a stimulus was presented. The Y axis gives the amplitudes (μV) of the ERPs in the recognition task of Experiment 1b. **<u>Panel b</u>**, mean peak latencies (ms) for the N170 component in all stimulus' conditions. **<u>Panel c</u>**, mean peak amplitudes (μV) for the N170 component in all stimulus' conditions.

N170 Data Analysis for Experiment 1a and b combined – *Recognition Phase*

As for the behavioural data, we conducted a 2 x 2 x 2 mixed model analysis for the N170 peak latency from the two experiments recognition phase combined.

We found no evidence for a three-way interaction in the latencies (*Face Orientation* x *Stimulation* x *Experiment*), $F(1, 108) = .881$, $p = .35$, $\eta^2_p < .01$. There was a significant main effect of *Face Orientation* $F(1, 108) = 34.30$, $p < .001$, $\eta^2_p = .24$, which confirmed that inverted faces elicited a delayed N170 compared to upright faces. Importantly, a significant interaction was found between *Face Orientation* and *tDCS Stimulation* $F(1, 108) = 4.55$, $p = .035$, $\eta^2_p = .04$. No main effect of tDCS was found $F(1, 108) = .141$, $p = .71$, $\eta^2_p < .01$. Paired *t* test analyses were conducted which revealed a significant inversion effect in the sham group (M=11.12, SE=1.73), $t(55) = 6.43$, $p < .001$, $\eta^2_p = .43$, and a significant inversion effect in the anodal group (M=5.03, SE=2.02), $t(55) = 2.49$, $p = .016$, $\eta^2_p = .10$ (Figure 8, Panel a). No difference was found between the N170 latency for upright stimuli in the anodal vs sham group, $t(55) =.018$, $p = .98$, $\eta^2_p <.01$. Despite a numerically delayed N170 for the inverted faces in the sham vs anodal group, no significant difference was found, $t(55) = .764$, $p = .44$, $\eta^2_p = .01$.

The same analysis applied to the N170 peak amplitude revealed no significant three-way interaction (*Face Orientation* x *Stimulation* x *Experiment*), $F(1, 108) = 2.86$, $p = .10$, $\eta^2_p = .02$. There was a significant main effect of *Face Orientation* $F(1, 108) = 78.19$, $p < .001$, $\eta^2_p = .42$, which confirmed that inverted faces elicited a larger N170 compared to upright faces. Importantly, a significant interaction was found between *Face Orientation* and *tDCS Stimulation* $F(1, 108) = 7.39$, $p = .008$, $\eta^2_p = .06$, which indicated that the inversion effect was larger in the anodal group. No main effect of tDCS was found $F(1, 108) = .287$, $p = .59$, $\eta^2_p < .01$. Paired *t* test analyses were conducted which revealed a significant inversion effect in the anodal group (M=1.81μV, SE=.32), $t(55) = 5.53$, $p < .001$, $\eta^2_p = .36$, and in the sham group (M=.956μV, SE=.22), $t(55) = 4.34$, $p < .001$, $\eta^2_p = .25$ (Figure 8, Panel b). No difference was found between the N170 peak for upright stimuli in the anodal vs sham group,

$t(55) = .094$, $p = .92$, $\eta^2_p < .01$. No significant difference was found between the inverted faces in the sham vs anodal group, $t(55) = 1.13$, $p = .26$, $\eta^2_p = .02$.

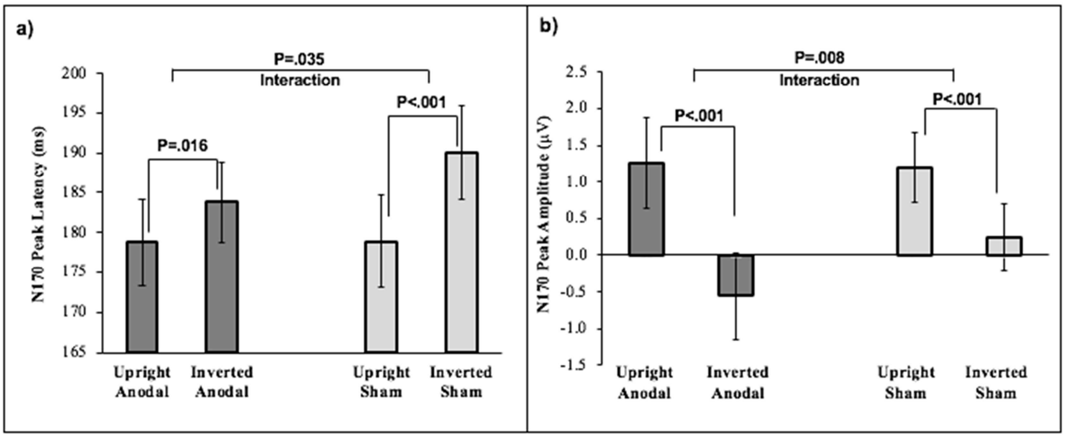

Figure 8. This illustrates the results from combining the N170 latency and amplitude data obtained from the recognition task in Experiment 1a & 1b. **Panel a**, mean peak latencies (ms) for the N170 component in all stimulus' conditions. **Panel c**, mean peak amplitudes (µV) for the N170 component in all stimulus' conditions.

General Discussion

In the two experiments reported in this paper we examined the effects of tDCS on the face inversion effect behaviourally and on the ERPs N170 peak component. Specifically, we extended the tDCS procedure adopted by Civile, Verbruggen et al (2016), Civile et al (2018), Civile et al (2019) and Civile et al (2020) to modulate the inversion effect for newly acquired stimuli (i.e. checkerboards) and long-term learnt stimuli i.e. faces. Importantly, this is the first study that attempted to combine tDCS and EEG simultaneously to examine the tDCS-induced effects on the face inversion effect on the N170 component.

The behavioural results from Experiment 1a showed that the anodal stimulation reduced the inversion effect compared to sham only numerically. We note that since Civile et al (2018), Civile et al (2019) and recently Civile et al (2020)'s work, this is the first time that the tDCS stimulation we use did not lead to a significantly reduced inversion effect in the anodal condition, however, it would be untrue to say that these results are out of line (numerically) with our previous research. Also, this is the first time that the tDCS significantly affected overall behavioural recognition performance compared to sham. One possible explanation for this (if it is not simply random variation) relates to differences in the tDCS application procedure necessitated by the concurrent EEG recording system used in Experiment 1a. Hence, the pressure exerted by the EEG cap (positioned on top of the tDCS electrode pads) in combination with the active stimulation may have raised the level of discomfort experienced by participants, consequentially producing a blanket reduction in overall performance. The behavioural results from Experiment 1b, essentially confirmed the effects found before in the literature showing that anodal tDCS over the Fp3 significantly reduces the face inversion effect compared to sham. In this case no effect of tDCS was found on overall recognition performance. It is once we combined the behavioural results from the two experiments that we obtained the strongest effects, perhaps suggesting that the individual experiments taken on their own needed a larger sample. The post-hoc sample size power analyses showed that Experiment 1a was underpowered, whereas Experiment 1b was in line with the recommended level of power (Cohen, 1988).

In line with what was found previously in Civile et al (2018), Civile et al (2019), and Civile et al (2020) 's studies, the results from both Experiment 1a and 1b show that anodal tDCS delivered at Fp3 site for 10 min at 1.5mA is able to affect the face inversion effect compared to sham (control) stimulation. And the overall Bayes Factor analysis provides additional support for the contention that the effects obtained are in line with previous work. Furthermore, previous studies (Civile et al., 2018; Civile et al., 2019; Civile et al., 2020) also found that anodal tDCS is effective in reducing the recognition performance for upright faces compared to sham. We did not find this result to be significant in each experiment taken on its own. However, when we combined the data for Experiment 1a and

1b we found that anodal tDCS significantly affected the recognition of upright faces compared to sham (this is also confirmed by the Bayes Factor analysis).

Importantly, from Civile, Verburggen et al (2016), McLaren et al (2016), Civile et al (2018), Civile et al (2019) and more recently Civile et al (2020)’s work we know that the behavioural effects found with the tDCS procedure adopted here are not just be a matter of making people worse at recognition performance overall. Empirically, there is the fact that Civile et al (2018), Civile et al (2019) and Civile et al (2020) have never observed a significant reduction in performance to inverted faces using this procedure (also Civile, Verbruggen et al 2016, found that tDCS did not affect inverted familiar checkerboards). In our experiments as well we found no effects of tDCS on the inverted faces. Critically, the behavioural results from Experiment 1a and b combined together confirmed what Civile et al (2018), Civile et al (2019) and Civile et al (2020) previously found, i.e. a reduction in performance for upright faces as a consequence of the tDCS procedure (see also Civile, Verbruggen et al 2016, for similar effects on upright familiar checkerboards). Based on the MKM theory of perceptual learning the effects of tDCS on the inversion effect have been interpreted as the result of a reconfiguration of the cognitive processing that develops representations of stimuli, such that instead of pre-exposure to a prototype-defined category enhancing the discriminability of the exemplars taken from that category, it instead now enhances generalization between them. This makes the common prototypical features of those exemplars more prominent rather than exaggerating the features unique to each exemplar that constitute their differences. It is this change in perceptual learning that causes the reduction in the face inversion effect because it reduces individuals’ ability to discriminate between different upright faces, which is normally enhanced by their expertise acquired via experience and manifesting as perceptual learning.

This suggests that the tDCS procedure is affecting face recognition by making the faces look more "similar". Thus, if tDCS affects configural processing for familiar stimuli by maintaining the salience of the prototypical features shared among the stimuli, we would expect from the behavioural results a reduced face inversion effect. We would also expect the results from the N170 latencies to be similar to the behavioural ones as a consequence of the upright faces becoming more difficult to recognize, and so closer to the latencies obtained for inverted faces.

The ERP results for N170 latency show that the tDCS procedure reduces the inversion effect compared to sham. Hence, less delay as a consequence of inversion was found on the N170 in the anodal condition compared to sham. The interaction between the reduction of the inversion effect on the N170 latency in the anodal group vs. that found in the sham group was significant in the Experiment 1b study phase data but not in the recognition task data. It is only once that we combined the ERP data from Experiment 1a and 1b that we find a significant interaction also in the recognition task (this is also confirmed by the Bayes Factor analysis). The fact that we find more robust effects in the study phase is in line with previous studies that examined the inversion effect of the N170 for checkerboards drawn from a familiar prototype-defined category (i.e. familiar configuration) vs that for checkerboards drawn from a novel prototype-defined category (Civile, Zhao, et al., 2014). It also agrees with studies that looked at the inversion effect on the N170, for normal faces vs that for sets of faces that had their configural information disrupted (e.g. scrambled, Thatcherised) (Civile, Elchlepp, et al., 2018; Civile et al., 2020). Given that modulation of the N170 latency reflects perceptual expertise to exploit the configural information, then this should occur when simply perceiving the stimulus and should be easiest to detect during the study phase. This is because the effect should not be tied to having to do anything in particular, except perhaps attend to the stimulus, and by the recognition phase our familiarity manipulation would have been somewhat diluted by experience of all the stimuli in the study phase. In the specific case of the tDCS there is also an additional potential explanation related to the specific duration of the effects induced and whether performance would be repristinated as “normal” after some time from the end of the stimulation. Future studies should investigate whether the effects of tDCS on face recognition (and more general perceptual learning) are long lasting or instead temporary. Overall the results from the N170 latency analysis are supported in the literature described in the introduction. Several studies have attributed the latency delay in response to inverted faces to the disruption of configural information (for a review see Eimer 2011). Hence, studies that broadly support the expertise-based account of the inversion effect on the N170 have shown how a similar delay in the latencies is recorded for prototype-defined artificial categories of stimuli (i.e. they share a configuration) other than faces (e.g. Greebles, fingerprints, checkerboards). This suggests that delay in the N170 is associated with disruption of the ability (developed with expertise) to exploit the configural information within a familiar stimulus (Rossion et al., 2002; Busey & Vanderkolk 2005; Civile, Zhao et al., 2014). Importantly, the tDCS procedure would seem to affect the inversion effect by inducing a similar reduction on the N170 latency to that usually recorded for sets of faces where the configural information has been disrupted (e.g. scrambled, Thatcherised, contour removed/scrambled faces). Our finding is essentially a first demonstration that the inversion effect on the N170 latency can be reduced in response to sets of regular faces that have all the configural information unaltered. Thus, we are able to argue that the tDCS procedure is able to influence configural processing. As predicted, our results on the N170 latency seems to reflect the behavioural results. Previous studies on the N170 and face inversion effect showed that configural disruption reduces the behavioural face inversion affect as well as that on the N170 latencies (e.g. Civile, Elchlepp, et al., 2018 using scrambled faces; Civile et al., 2020 using Thatcherised faces). In a similar vein, the tDCS procedure in the studies reported here was able to reduce the inversion effect behaviourally and on the N170 latency compared with sham. Future studies should seek to directly determine how tDCS affects the N170 peak latency for upright and inverted faces.

This brings us to the results for the N170 peak amplitudes. We know from the literature that inverted faces not only elicit a delayed but sometimes also a larger N170 component compared to that elicited by upright faces (Eimer 2000; Sagiv & Bentin, 2001). The results from the experiments reported here suggest that applying the tDCS procedure increases the inversion effect on the N170 amplitudes compared to the sham group. As for the case of the N170 latency results, we find that the effects obtained were stronger in the Experiment 1b study phase although a significant interaction was also found in the recognition task data from Experiment 1a. Once we combined the data from the recognition task in Experiment 1a and 1b the effects were highly significant (i.e. larger inversion effect in the anodal condition vs. sham). In general, these results would seem to support at least in part Lafontaine et al (2013)'s study, by suggesting that tDCS at DLPFC increases the N170 amplitudes, however we see this happening only numerically and mainly in response to the inverted faces. As well as in Lafontaine et al (2013)'s study, this increase in the N170 amplitude is not linked with any increase in behavioural performance, rather there is a decrease in performance to upright faces.

One potential explanation for these results is based on previous studies that investigated the relevance of the eyes considered as specific features that we rely on, in addition to configural processing, when we recognize faces. Itier, Latinus and Taylor (2006) showed that presenting isolated upright eyes elicits a larger N170 amplitude (at occipital P8 channel area) compared to that found for the whole upright human face, ape faces and various categories of objects (e.g. chairs, cars, houses). Furthermore, Itier et al (2007) showed that in contrast to whole faces, inversion of eyeless faces (the eyes were removed, and the space left empty was blended in grey) reduced the face inversion effect on the N170 amplitude. Nemrodov, Anderson, Preston and Itier (2014) using eye tracking and EEG demonstrated that a larger N170 was found when fixation was enforced on the eyes compared to fixation on the forehead, nasion, nose, or mouth. In order to enforce fixation, participants were instructed to fixate in the centre of the screen, however, the faces were offset in such a way that gaze fixated the different face locations (e.g. the eyes or the nose). Critically, in both upright and inverted conditions the eyes elicited the largest N170 amplitude. Enforcing fixation on the eye region of eyeless faces, however, made the increased N170 amplitude disappear. We suggest that the increased inversion effect on the N170 amplitudes recorded in the anodal condition in our Experiment 1a and 1b could potentially indicate a switch from configural processing to a more feature-based processing that enhances the effect of the eyes of the faces. Future studies should investigate potential stimulus manipulations (e.g. eyeless faces) that could help to disentangle the tDCS-induced effects on the inversion effect and the N170 component.

Overall, our results suggest that our tDCS procedure is able to *behaviourally* influence the face inversion effect by reducing it compared to sham. Thus, the behavioural results from our study find support in the perceptual learning literature and specifically previous studies that have looked at the effects of the same tDCS procedure on the inversion effect (Civile, Verburggen et al., 2016; McLaren et al., 2016; Civile et al., 2018; Civile et al., 2019; Civile et al., 2020). Taken all together, the results from previous studies and the study reported here provide some robust evidence for the use of the tDCS procedure as a powerful method to influence perceptual learning. The results from the ERPs show that the tDCS procedure is also able to reduce the face inversion effect on the N170 latency. These results find support in the N170 and face inversion effect literature, and specifically in the accounts based on configural processing. Finally, the results from the N170 amplitudes show a "novel" pattern indicating that the tDCS procedure would seem to elicit a larger inversion effect on the specific component. This effect finds some parallels in the N170 and face vs eye and eyeless faces inversion effect literature.

One may notice that the ERP results in our study were more robust in the Experiment 1b study phase than in the Experiment 1a and 1b recognition phases (although after we combined them these results were also robust). One potential explanation is based on the fact that during the recognition task participants have already developed some familiarity with the inverted stimuli (at least half of them) and so the effects of stimulus exposure may have been attenuated. Previous studies have found a similar effect (e.g. Civile, Zhao et al., 2014 using checkerboards; Civile, Elchlepp et al., 2018 using scrambled faces; Civile et al., 2020 using Thatcherised faces). Alternatively, it could be that having to make a decision and respond is responsible for attenuating this effect. Yet another potential explanation is that the effects of the tDCS may be stronger when the stimulation is active and perhaps, they start to diminish once it has ended (at the end of the study phase). Future studies should systematically investigate the effects of the tDCS procedure when delivered during the study phase (i.e. encoding of the faces) vs when delivered during the recognition task only.

Future studies should also address the question around the specific type of configural processing affected (e.g. first/second relational information vs holistic) by the tDCS. Hence, the same tDCS procedure might be extended to specific phenomena linked to holistic processing like for example the composite face effect. Only two studies have so far investigated the influence of tDCS on the composite face effect. Both studies applied the anodal stimulation at occipital areas and found in one case (Yang et al., 2014) a reduction of the composite effect by means of improved recognition performance. However, Renzi et al (2014) found that unlike Yang at el (2014), anodal tDCS delivered over occipital areas did not influence the composite face effect. Moreover, future studies should extend the tDCS procedure in combination with EEG recordings to investigate the effects on face identity recognition. While the N170 component appears to be insensitive to face familiarity, or repetitions, another component called N250r is typically found to be larger in response to familiar vs unfamiliar faces. Thus, it has been associated with individual recognition (Schweinberger, Huddy & Burton, 2004).

In conclusion, the work reported in this paper highlights the effects of tDCS on face recognition skills indexed by the face inversion effect. Importantly, we provide the basis for a novel technique that uses tDCS and EEG combined simultaneously to investigate the mechanisms underpinning the face inversion effect and more generally face recognition.

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References

Anaki, D., Zion-Golumbic, E., and Bentin, S. (2007). Electrophysiological neural mechanisms for detection, configural analysis and recognition of faces. *Neuroimage 37, 1407–1416*.

Ambrus G., Zimmer M., Kincses Z., Harza I., Kovacs G., Paulus W., et al. (2011). The enhancement of cortical excitability over the DLPFC before and during training impairs categorization in the prototype distortion task. *Neuropsychologia 49*, 1974–1980.

Bentin, S., Allison, T., Puce, A., Perez, E., and McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience, 8, 551 –565*.

Busey, T., and Vanderkolk, J. (2005). Behavioural and electrophysiological evidence for configural processing in fingerprint experts. *Vision Research, 45, 431–448*.

Carmel, D., and Bentin, S. (2002). Domain specificity versus expertise: Factors influencing distinct processing of faces. *Cognition, 83, 1–29*.

Civile, C., Obhi, S.S., and McLaren, I.P.L. (2019). The role of experience-based perceptual learning in the Face Inversion Effect. *Vision Research, 157, 84-88*.

Civile, C., Elchlepp, H., McLaren, R., Galang, C.M., Lavric, A., and McLaren, I.P.L. (2018a). The effect of scrambling upright and inverted faces on the N170. *Quarterly Journal of Experimental Psychology, 71, 2464-2476*.

Civile, C., McLaren, R., and McLaren, I.P.L. (2018). How we can change your mind: Anodal tDCS to Fp3 alters human stimulus representation and learning. *Neuropsychologia, 119, 241-246*.

Civile, C., McLaren, R., and McLaren, I.P.L. (2016). The face inversion effect: Roles of first and second-order relational information. *The American Journal of Psychology, 129, 23-35*.

Civile, C., Verbruggen, F., McLaren, R., Zhao, D., Ku, Y., and McLaren, I.P.L. (2016). Switching off perceptual learning: Anodal transcranial direct current stimulation (tDCS) at

Fp3 eliminates perceptual learning in humans. *Journal of Experimental Psychology: Animal Learning and Cognition, 42, 290-296.*

Civile, C., Zhao, D., Ku, Y., Elchlepp, H., Lavric, A., and McLaren, I.P.L. (2014). Perceptual learning and inversion effect: Recognition of prototype-defined familiar checkerboards. *Journal of Experimental Psychology: Animal Learning and Cognition, 40, 144-161.*

Civile, C., McLaren, R., and McLaren, I.P.L. (2014). The face Inversion Effect-Parts and wholes: Individual features and their configurations. *Quarterly Journal of Experimental Psychology*, *67, 728-746*.

Civile, C., McLaren, R. and McLaren, I.P.L. (2011). Perceptual learning and face recognition: Disruption of second-order relational information reduces the face inversion effect. In L. Carlson, C. Hoelscher, and T.F. Shipley (Eds.), *Proceedings of the 33rd Annual Conference of the Cognitive Science Society,* (pp. 2083-88). Austin, TX: Cognitive Science Society.

Civile, C., Cooke, A., Liu, X., McLaren, R., Elchlepp, H., Lavric, A., Milton, F., and I.P.L. McLaren. (2020). The effect of tDCS on recognition depends on stimulus generalization: Neuro-stimulation can predictably enhance or reduce the face inversion effect. *Journal of Experimental Psychology: Animal Learning and Cognition*, *46, 83-98*.

Cohen, J. (1988). Statistical power analysis for the behavioural sciences (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum.

Diamond, R. and Carey, S. (1986). Why faces are and are not special: An effect of expertise. *Journal of Experimental Psychology: General*, *115, 107-117.*

Dienes, Z., (2011). Bayesian versus orthodox statistics: which side are you on? *Perspective in Psychological Science, 6, 274–290*.

Eimer, M. (2000). Effects of face inversion on the structural encoding and recognition of faces. Evidence from event-related brain potentials. *Cognitive Brain Research, 10, 145–158.*

Eimer, M. (2011). “The face-sensitive N170 component of the event-related potentials,” in *The Oxford Handbook of Face Perception*, eds A. J. Calder, G. Rhoades, M. N. Johnson, and J. V. Haxby (Oxford: Oxford University Press), 329–344.

Gauthier, I., and Tarr, M. (1997). Becoming a “Greeble” expert: exploring mechanisms for face recognition. *Vision Research, 37, 1673-1682.*

Goffaux, V., & Rossion, B. (2006). Faces are ‘‘spatial” – Holistic face perception is supported by low spatial frequencies. *Journal of Experimental Psychology: Human Perception and Performance, 32, 1023–1039.*

Bötzel, K. & Grüsser, O.J. (1989). Electric brain potentials evoked by pictures of faces and non-faces: a search for face-specific EEG-Potentials. *Experimental Brain Research, 77, 349 – 360.*

Itier, R.J., Latinus, M., and Taylor, M.J. (2006). Face, eye and object early processing: What is the face specificity? *Neuroimage, 29, 667 – 676.*

Itier, R.J., Alain, C., Sedore, K., and McIntosh, A.R. (2007). Early face processing specificity: It’s in the eyes! *Journal of Cognitive Neuroscience*,19 , 1815–1826.

Jacques, C., and Rossion, B. (2007). Early electrophysiological responses to multiple face orientations correlate with individual discrimination performance in humans. *Neuroimage 36, 863–876*.

Jeffreys, D.A., Tukmachi, E.S.A., and Rockley, G. (1992). Evoked-potential evidence for human brain mechanisms that respond to single fixated faces. *Experimental Brain Research*, 91, 351–362.

Joyce, C. and Rossion, B. (2005). The face-sensitive N170 and VPP components manifest the same brain processes: The effect of reference electrode site. Clinical Neurophysiology, 116, 2613–2631.

Kincses, T. Z., Antal, A., Nitsche, M. A., Bártfai, O., and Paulus, W. (2004). Facilitation of probabilistic classification learning by transcranial direct current stimulation of the prefrontal cortex in the human. *Neuropsychologia, 42, 113–117*.

Lafontaine MP, Theoret H, Gosselin F, Lippe S (2013). Transcranial direct current stimulation of the dorsolateral prefrontal cortex modulates repetition suppression to unfamiliar faces: an ERP study. *PloSone 8: e81721*.

Marzi, T., and Viggiano, M., (2007). Interplay between familiarity and orientation in face processing: an ERP study. *International Journal of Psychophysiology 65, 182–192*.

Maurer, D., Le Grand, R., and Mondloch, C. (2002). The many faces of configural processing. *Trends in Cognitive Science, 6, 255–260*.

McLaren, I.P.L., Carpenter, K., Civile, C., McLaren, R., Zhao, D., Ku, Y., Milton, F., and Verbruggen, F. (2016). Categorisation and Perceptual Learning: Why tDCS to Left DLPC enhances generalisation. *Associative Learning and Cognition*. Homage to Prof. N.J. Mackintosh. Trobalon, J.B., and Chamizo, V.D. (Eds.), University of Barcelona.

McLaren, I.P.L (1997). Categorization and perceptual learning: An analogue of the face inversion effect. *The Quarterly Journal of Experimental Psychology 50, 257-273.*

McLaren, I.P.L., and Civile, C. (2011). Perceptual learning for a familiar category under inversion: An analogue of face inversion? In L. Carlson, C. Hoelscher, & T.F. Shipley (Eds.), *Proceedings of the 33rd Annual Conference of the Cognitive Science Society*, (pp. 3320-25). Austin, TX: Cognitive Science Society.

McLaren, I.P.L., Kaye, H. & Mackintosh, N.J. (1989). An associative theory of the representation of stimuli: Applications to perceptual learning and latent inhibition. In R.G.M. Morris (Ed.) *Parallel Distributed Processing - Implications for Psychology and Neurobiology*. Oxford, Oxford University Press.

McLaren, I.P.L. & Mackintosh, N.J. (2000). An elemental model of associative learning: Latent inhibition and perceptual learning. *Animal Learning and Behavior*, 38, 211-246.

Murphy, J., Gray, K. L. H., & Cook, R. (2017). The composite face illusion. *Psychonomic Bulletin & Review*, 24, 245-261.

Nemrodov, D., Anderson, T., Preston, F.F., Itier, R.J., 2014. Early sensitivity for eyes within faces: a new neuronal account of holistic and featural processing. *Neuroimage* 97, 81–94.

Righart, R., and de Gelder, B. (2006). Context influences early perceptual analysis of faces—an electrophysiological study. *Cerebral Cortex 16, 1249–1257.*

Rossion, B., and Corentin. J. (2011). The N170: understanding the time-course of face perception in the human brain. In: Steven J. Luc, The Oxford Handbook of Event-Related Potential Components, Oxford University Press: (United Kingdom) Oxford 2011, p. 115-142.

Rossion, B., Gauthier, I., Goffaux, V., Tarr, M.-J., Crommelinck, M. (2002). Expertise training with novel objects leads to face-like electrophysiological responses. *Psychological Science, 13, 250-257.*

Rossion, B., Gauthier, I., Tarr, M.J., Despland, P., Bruyer, R., Linotte, S., and Crommelinck, M. (2000). The N170 occipito-temporal component is delayed and enhanced to inverted faces but not to inverted objects: an electrophysiological account of face-specific processes in the human brain. *Neuroreport, 11, 69 – 74.*

Tanaka, J. W., & Farah, M. J. (1991). Second-order relational properties and the inversion effect: Testing a theory of face perception. *Perception & Psychophysics, 50, 367–372.*

Tanaka, J.W. and Farah, M.J. (1993). Parts and wholes in face recognition. *Quarterly Journal of Experimental Psychology, 46, 225–245.*

Tanaka, J.W. and Sengco, J. (1997) Features and their configuration in face recognition. *Memory & Cognition, 25, 583–592.*

Seger, C., Poldrack, R., Prabhakaran, V., Zhao, M., Glover, G., Gabrieli, J., et al. (2000). Hemispheric asymmetries and individual differences in visual concept learning as measured by functional MRI. *Neuropsychologia, 38, 316–1324*.

Sagiv, N., and Bentin, S. (2001). Structural encoding of human and schematic faces: Holistic and part-based processes. *Journal of Cognitive Neuroscience, 13, 937 – 951*.

Schweinberger, S. R. Huddy, V. Burton, A. M. (2004). N250r: A face-selective brain response to stimulus repetitions. *Neuroreport, 15, 1501–1505*.

Valentine, T., and Bruce, V. (1986). Recognizing familiar faces: The role of distinctiveness and familiarity. *Canadian Journal of Psychology*, 40, 300-305.

Zion-Golumbic, E., & Bentin, S. (2007). Dissociated neural mechanisms for face detection and configural encoding: Evidence from N170 and Gamma-band oscillation effects. *Cerebral Cortex, 17, 1741–1749*.

Yang, L-Z., Zhang, W., Shi, B., Yang, Z., Wei, Z., Gu, F., Zhang, J., Cui, G., Liu, Y., Zhou, T., Zhang, X., and Rao, H. (2014). Electrical Stimulation over bilateral occipito-temporal regions reduces N170 in the right hemisphere and the Composite Face Effect. *PLoS ONE 9(12): e115772. pmid:25531112.*

Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology, 81, 141-145.*

Yovel G., and Kanwisher N. (2005) The neural basis of the behavioral face-inversion effect *Current Biology, 15, 2256- 62*.

- In Experiment 1a & 1b, we show that anodal tDCS delivered (10 mins at 1.5mA) over the left DLPFC at Fp3 significantly reduces the behavioral face inversion effect relative to sham (control) condition under double blind conditions.
- The ERP results provide some evidence for tDCS being able to influence the face inversion effect on the N170. Specifically, for the *N170 latencies* the tDCS reduces the usual face inversion effect (delayed N170 in response to inverted vs. upright faces) compared to sham. Contrarily, the same tDCS procedure increased the inversion effect seen in the *N170 amplitudes*.