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The Effects of transcranial Direct Current Stimulation on Perceptual Learning for Upright Faces and its Role in the Composite Face Effect

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Abstract

In the three experiments reported here we show that a specific neurostimulation method, whose influence can be understood in terms of a well-known theory of stimulus representation, is able to affect face recognition skills by impairing participants' performance for upright faces. We used the *transcranial Direct Current Stimulation* (tDCS) procedure we have recently developed that allows perceptual learning, as indexed by the face inversion effect, to be modulated. We extended this tDCS procedure to another phenomenon, the *composite face effect*, which constitutes better recognition of the top half of an upright face when conjoined with a *congruent* (in terms of the response required) rather than *incongruent* bottom half. All three experiments used the Face-Matching task traditionally used to study this phenomenon. Experiment 1a (n=48) showed that anodal tDCS (using a double-blind between-subjects design) delivered at Fp3 (10 mins at 1.5mA) affected overall performance for upright faces compared to sham but had no effect on the composite face effect itself. Experiment 1b (n=48) replicated our usual tDCS-induced effects on the face inversion effect but this time using a Face-Matching task instead of the old/new recognition task previously employed to obtain the effect. Importantly, Experiment 2 (n=72) replicated the findings from Experiment 1a, and, using an active control group, showed that the Fp3 anodal tDCS effects on performance to upright faces are not obtained when a different brain area is targeted. We interpret our results in the light of previous literature on the tDCS effects on perceptual learning and face recognition and suggest that different mechanisms are involved in the face inversion effect and the composite face effect.

Key Words: tDCS, Perceptual Learning; Face Recognition; Composite Face Effect.

Exposure to, or experience with, a set of stimuli generated from the same prototype-defined category can enhance our performance when we are called upon to recognize those stimuli. The phenomenon that leads us to this improvement is referred to as perceptual learning (James, 1890; Gibson, 1969) and this has been used to investigate the mechanisms of one of the best cognitive skills we have, face recognition. Generally, individuals can recognize a familiar face within a few hundred milliseconds, and, after a quick glimpse, they can extract the key information necessary to categorize a person's facial expression, demographics (e.g. gender, approximate age, ethnicity) and eye gaze direction (Haxby, Hoffman & Gobbini, 2000; Bruce & Young, 1986).

A key debate in the literature concerns the nature of our face recognition skills and several authors have investigated this by studying the factors that influence a robust phenomenon known as the face inversion effect (Yin, 1969; Valentine & Bruce, 1986; Yovel & Kanwisher, 2005; Civile, McLaren & McLaren, 2014). This refers to better performance when we try to recognize (as recently seen) faces presented in their usual upright orientation compared to when we see them turned upside down (i.e. inverted). When it was first discovered, the face inversion effect was interpreted as a marker for the "specificity" of face recognition skills. This was mainly because the size of the inversion effect for faces was larger than that obtained in response to other visual stimuli such as houses or planes (Yin, 1969; Valentine & Bruce, 1986; Yovel & Kanwisher, 2005). However, Diamond and Carey (1986) introduced "expertise" as one of the main factors responsible for the face inversion effect by showing that a large inversion effect could also be obtained with dog images when participants were dog breeders (i.e. experts with a great deal of exposure to dogs). Hence, they proposed that in recognizing faces we rely on our experience with configural information. This includes sensitivity to the spatial relationships among the main features within a stimulus (i.e. first-order relations), and the variations in spatial relations relative to the prototype for that stimulus set (i.e. second-order relations). On inversion, our ability to exploit such information is disrupted, resulting in reduced recognition performance. Thus, a robust inversion effect should be obtained for all those sets of stimuli that share a base configuration (i.e. prototype) that we have the necessary expertise for. In support of the expertise account, other researchers provided evidence for the inversion effect in response to novel categories of mono-orientated artificial objects named Greebles after participants have become familiar with them (Gauthier & Tarr, 1997; see also Tanaka and Farah, 1991 for an example of an inversion effect with dot patterns). But, perhaps the strongest evidence in support of the expertise account of face recognition comes from the perceptual learning literature.

In 1997, McLaren provided the first evidence of a robust inversion effect for prototype-defined categories of checkerboards as predicted by a model of perceptual learning, the MKM model (McLaren et al., 1989; McLaren & Mackintosh, 2000). Then Civile, Zhao et al (2014) extended McLaren's (1997) findings to the *old/new recognition task* typically employed in the literature to study the inversion effect (Yin, 1969; Diamond & Carey, 1986; Robbins & McKone, 2007; Civile, McLaren, & McLaren, 2011; McLaren & Civile, 2011, Civile et al., 2014; Civile, McLaren & McLaren, 2016). In Civile, Zhao et al's (2014) study participants were first engaged in a categorization task (the pre-exposure phase) where they were asked to sort a set of checkerboards drawn from two prototype-defined categories presented one at a time in random order. Following this, participants were asked to memorize a set of novel checkerboards (during the study phase) half of which were drawn from one of the two familiar categories they had previously seen, with some of them presented upright (same orientation as that familiarized during the categorization task) and the others inverted (rotated by 180 degrees). The other half was drawn from a novel category not seen before during the categorization task with some exemplars presented upright and some inverted. Because the checkerboards used do not have a predefined orientation, i.e. they are non mono-orientated stimuli, for those drawn from a novel category, the participants had no experience of upright or inverted orientation. Hence, they served as baseline for the inversion effect investigated in response to the checkerboards drawn from the familiar category. In the final old/new recognition task, participants were asked to recognize which of the checkerboards, shown one at a time, they had seen previously in the study phase. The "old" checkerboards were intermixed with new checkerboards split by the same four stimulus conditions that applied to those seen in the study phase (i.e. familiar upright/inverted, novel upright/inverted). The results showed a robust inversion effect for checkerboards drawn from a familiar category vs that for the novel category, mainly because performance to the upright checkerboards from the familiar category was rather better than for checkerboards taken from the novel category.

The basis of the inversion effect for stimuli drawn from a familiar prototype-defined category can be explained by the MKM model of perceptual learning. Specifically, the model predicts that it is elements that are relatively unpredicted by other elements present that will be salient, whereas those that are well predicted (by other elements of the stimulus) will be less salient. This follows from the salience modulation mechanism contained within the model, and is a mechanism that gives rise to perceptual learning as a consequence of stimulus pre-exposure. For example, in Civile, Zhao et al (2014) in the categorization task (i.e. the pre-exposure phase) participants learn how to categorize checkerboard exemplars drawn from two different categories. Each exemplar is constructed by adding noise to a prototype, and so each exemplar contains prototypical features or elements that have not been changed as well as new features or elements that have. The former elements are those that the category prototype and the exemplars would tend to have in common. Due to the fact that these common elements are presented at every trial they would tend to lose their salience because of the associations that form between them. Specifically, the model predicts that strong associations would be formed when one element reliably predicts another because an error correcting learning rule is used. Consequently, the common elements become more predicted by associations because they are encountered every time an exemplar is processed, and they are reliably predicted by many of the other elements present in the exemplar. Thus, when the categorization task ends these common elements would be strongly associated with the correct category because of the reliable pairing between them and it, but will now be relatively slow to form new associations because of the strong associations between these elements. This leads to perceptual learning, in this case heightened discriminability between exemplars from a given category, because the elements unique to each exemplar will still have relatively high salience due to their low exposure and the lack of other elements predicting them. When subjects are asked to discriminate between category exemplars it should be easier for them to do so considering that the salience of the elements that those exemplars share in common has now decreased, whereas that of the elements that distinguish them is still high. Critically, this advantage would be lost on inversion, because we assume that stimulus representations are orientation specific, and so subjects are not familiar with the exemplars turned upside down; hence, the unique elements of an exemplar would no longer enjoy any salience advantage over the elements common to most exemplars and the prototype (McLaren et al., 1989; McLaren & Mackintosh, 2000; McLaren, 1997; McLaren & Civile, 2011; Civile, Zhao et al., 2014).

In recent years, a new line of research developed by Civile, Verbruggen et al (2016) first, and then extended by Civile, McLaren and McLaren (2018), Civile, Obhi and McLaren (2019) and Civile et al (2020), has provided additional evidence for the role of perceptual learning in face recognition skills by strengthening the analogy between the inversion effect for checkerboards (Civile, Zhao et al., 2014) and that for faces (Yin, 1969; Civile et al., 2014;

Civile et al., 2016). Through the use of a particular tDCS procedure, they were able to provide evidence that the inversion effect for checkerboards and that for faces shared at least some of the same causal mechanisms. The tDCS apparatus consisted of a target channel electrode and a reference channel electrode both placed on the scalp and delivering through them a continuous low electro-current stimulation typically between 1-2mA (Nitsche, Cohen, et al., 2008). When the active anodal stimulation was delivered, the current would induce depolarization of the resting membrane potential which increases neural excitability and allows for more spontaneous cell firing. The sham stimulation served as a control, and in this condition, tDCS is only delivered for a brief period of time (usually 30 sec in total), not enough to induce any changes (Radman et al., 2009).

In 2011, Ambrus et al had examined the effects of anodal tDCS delivered over the left dorsolateral prefrontal cortex at Fp3 on performance during a categorization learning task testing the prototype distortion effect. This effect refers to the increased performance at categorizing category prototypes vs category exemplars, neither of which subjects had previously been trained on. This specific brain region was targeted with tDCS because of a previous fMRI study showing increased brain activation during a categorization task involving two sets of prototype-defined checkerboards (Seger et al., 2000). The results from Ambrus et al's (2011) study showed that anodal stimulation eliminated (compared to sham) the prototype distortion effect by reducing categorization performance for the category prototypes (see also McLaren et al., 2016 and Kincses et al, 2013 for other studies that have used the same tDCS procedure on categorization learning tasks). Civile, Verbruggen et al (2016) adopted the same tDCS procedure developed by Ambrus et al (2011) and applied it to the same old/new recognition task used in Civile, Zhao et al's (2014) study which obtained an inversion effect with checkerboards. Using a double-blind between-subjects design, anodal tDCS was delivered at the Fp3 site (for 10 mins at 1.5mA) while subjects performed the categorization learning task with the two prototype-defined categories of checkerboards. The results from the recognition task that followed this showed that the inversion effect that would otherwise be obtained for checkerboard exemplars drawn from a familiar category was abolished; and it was significantly different to the sham condition which demonstrated the expected effect. Critically, this finding was mainly due to a reduction in recognition performance for upright stimuli.

To test the correspondence between the inversion effect for checkerboards and that for faces, Civile et al (2018), Civile et al (2019), and more recently Civile et al (2020), extended the same tDCS procedure to the face inversion effect. Thus, tDCS stimulation (anodal or sham) was delivered while the subjects were asked to memorize a set of upright and inverted faces presented one at a time in random order. The results from the following recognition task revealed that, as for the checkerboards, the face inversion effect was significantly reduced by the anodal stimulation compared to sham. It was also the case that recognition performance for upright faces in the anodal condition was significantly changed (reduced) compared to that in the sham condition. Furthermore, Civile et al (2018, Experiment 3) conducted an *active control* experiment where a separate group of subjects were presented with the same old/new recognition task, however, this time a different brain area was targeted (Right Inferior Frontal Gyrus) with the anodal and sham tDCS. The results showed no effects of the tDCS on the face inversion effect. Overall, these results reveal how a relatively brief tDCS stimulation can significantly affect the face inversion effect, and this suggests that, by analogy with the result obtained with checkerboards, this is attributable, at least in part, to an effect on perceptual learning.

Based on the MKM model, Civile, Verbruggen et al (2016) Civile et al (2018), Civile et al (2019), and Civile et al (2020) suggested that the tDCS procedure affects perceptual learning by disrupting the salience modulation mechanism that would normally produce perceptual learning for upright stimuli. *Figure 1* below gives a schematic representation of the salience modulation in normal circumstances and under the tDCS procedure. *Panel a,* illustrates (in red) one exemplar that possesses common prototypical elements (**x**) that it shares with other exemplars, and unique elements (**c**). *Panel b* instead illustrates how salience modulation would change on the MKM model as a result of exposure to exemplars drawn from the same category (top curve in grey). The associations between **x** elements and between **c** and **x** elements quickly build up and, as a consequence, the salience of the **x** elements falls rapidly. The relatively novel **c** elements will not suffer much of a decline in salience, and so will become relatively salient, making it easier to learn about specific exemplars after the experience with the category, even if those exemplars have not been seen before. The lower curve (black line) shows how salience would change if error-based modulation (i.e. based on elements reliably predicting others) was not in operation as would be the case for McClelland and Rumelhart (1985). Now, as learning progresses, salience increases rather than decreasing, because the associations between elements contribute to the total activation of each element. This means that the common, **x** elements will typically be at an advantage in terms of salience / activation compared to the unique, **c** elements. The implication is that such a system will be better at learning about commonalities than differences. Our proposal is that this would be the case of when the tDCS procedure is applied. Now, as learning progresses, salience for the common elements increases rather than decreases. This means that the common **x** elements will typically be at an advantage in terms of salience/activation compared to the unique **c** elements. The implication is that such a system will now be better at learning about commonalities (i.e. the common elements) than differences (i.e. unique elements). The tDCS manipulation can be seen as preventing error-based modulation of salience, resulting in enhanced *generalisation* expressed as increased learning about the common elements between the exemplars. This would make it harder to use the unique elements typical of each exemplar in order to discriminate it from other similar exemplars. Thus, the inversion effect seen with checkerboards and that for faces would be impacted by considerably reduced performance for upright stimuli.

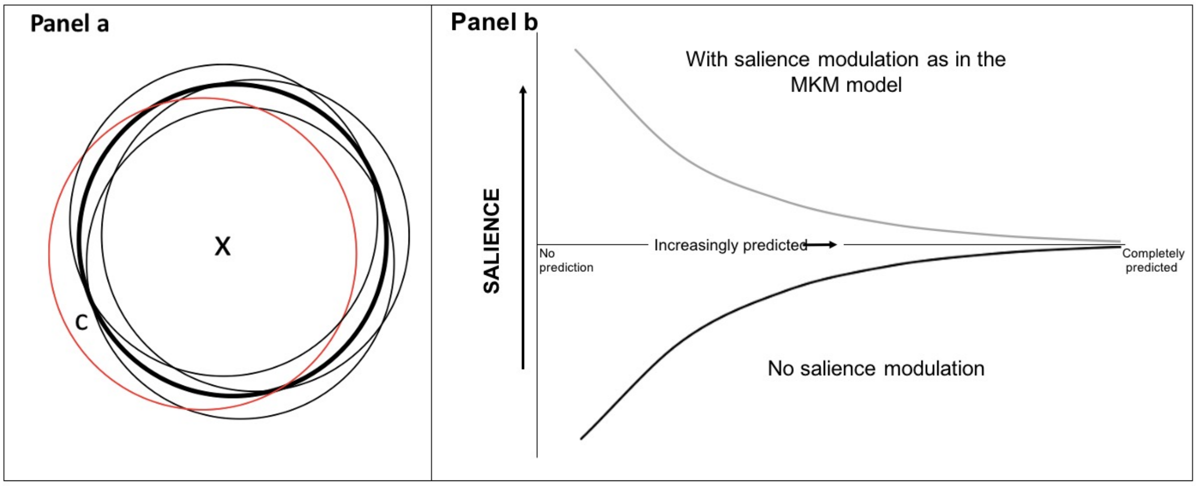

Figure 1. **Panel a** shows how a prototypical stimulus (bold circle) can be represented as a set of elements, and how that set changes when the prototype is distorted to produce exemplars (other circles). The circle shown red is one of such exemplars. **Panel b** shows how element salience changes in the MKM model as associations build up (top curve in grey) and how it would change without modulation of salience (bottom curve in black).

This learning-based process and the related tDCS-induced effects only apply to upright stimuli. This is because we have little or no experience in seeing for example faces presented upside down and so recognition performance is not aided by any significant amount of perceptual learning for stimuli in this orientation. The basic idea behind this is that experience would lead to every given facial feature at a given location within an upright face activating elements – a location specific representation. In addition, the combinations of features in specific locations would activate some elements. Importantly, these elements would differ from those activated by the same features if moved to another location, for example when inverted. Hence, when a face is inverted, the features are no longer in the same locations, and so a novel pattern of activation of the elements is produced, thus we have an orientation-specific representation of a face. The results from McLaren (1997), McLaren and Civile (2011) and Civile, Zhao et al (2014) would support that by showing that pre-exposure to prototype-defined checkerboards leads to improved recognition performance for “upright” (the familiarised orientation) exemplars compared to those “inverted” (rotated by 180 degrees).

This brings us to the key aim of the current study. To further investigate the effects of tDCS on perceptual learning and face recognition skills, we applied our tDCS procedure to an experimental design that could directly test the effects of tDCS on upright faces presented on their own (i.e., not with inverted faces). We adopted the *composite face effect* paradigm from the face recognition literature for this purpose, as it is a paradigm wholly based on upright faces presented in different combinations. The effect itself manifests as greater difficulty in matching the top half of one face presented in composite with the bottom half of another face when the halves are aligned than when the two halves are offset laterally (misalignment). When we perceive the main features within an upright face arranged so as to form the prototypical configuration (preserving first-order relations for a face), we would tend to process the face as a gestalt making it more difficult to analyze the individual features. This *holistic* processing has been suggested as the basis of the composite face effect as demonstrated by the fact that when an upright composite face is presented, the internal features are so strongly integrated that it becomes harder to parse the two halves, leading the aligned composite to be perceived as a “new” face (Murphy, Grey, & Cook, 2017). Holistic processing is considered a type of configural processing (for a review Maurer et al., 2002; see also Rezlescu et al., 2012 for a direct comparison between the perceptual processes elicited by the inversion effect and the composite effect). Holistic processing also occurs between the internal features and the external contour of a face making it extremely difficult to recognize the internal features of a familiar face when presented within a different external contour.

Whereas the literature on the inversion effect makes the case for the role that expertise plays in producing the effect, for the composite effect the debate as to whether expertise is an important factor is still largely open. In particular, there have been relatively few studies that have shown a composite effect for non-face objects using the original matching task procedure. For example, Greebles experts failed to exhibit a composite effect for Greebles (Gauthier et al., 1998; Gauthier & Tarr, 2002). Similarly, dog experts failed to show a composite effect when presented with composite stimuli constructed from dog stimuli (Robbins & McKone, 2007). Perhaps the strongest evidence in support of the expertise account is that from Willems et al's (2014) study showing a composite effect for body posture stimuli.

To date, only two studies have investigated the effects of tDCS on the composite face effect. Yang et al., (2014, Experiment 2) investigated the effects of symmetric bilateral tDCS (right anodal left cathodal, right cathodal left anodal, sham) delivered at occipital-temporal sites (P7 on the left and P8 on the right based on a 20-channel EEG cap) on the behavioural composite face effect and its electrophysiological correlates. The specific area of stimulation was chosen based on the most studied "face-sensitivity" event-related potential (ERP) component; the N170 (for a review see Eimer 2011). In a single-blind and within-subjects design study, participants performed the same composite face task across three different tDCS conditions separated by at least 72 hours. The task included a practice phase, followed by a test phase. The stimuli used were composite faces made by combining the top half of a face and the bottom half of another face. Each trial started with a fixation cross followed by a composite face (target), followed by a mask, followed by a second composite face (test) which participants responded to by indicating (by pressing different keys) whether the top half was the same or different to that seen in the target composite face. The authors adopted a complete composite effect design (Richler, Cheung, & Gauthier, 2011; Richler et al., 2011).

This means that the composite faces could be congruent or incongruent, and the two halves could be aligned or misaligned. Congruent trials occur when the top half and bottom half of the face are such as to facilitate the required response. For example, if the first half has top half A and Bottom half B, i.e (A+B), and then the test face has (A+B) as well, then this makes a "same" response easier because the irrelevant bottom half supports that decision. The congruent trial type for a "different" response would be (A+B) followed by (C+D), as again both halves of the test face support the “different” response. Incongruent trials are, in some sense, the opposite. An incongruent same trial would be (A+B) followed by (A+C), and incongruent different, (A+B) followed by (C+B) because here the irrelevant bottom half promotes the opposite response to the top half. In line with previous literature, the results from the accuracy data revealed a significant congruency effect in aligned faces (i.e. higher performance for congruent vs incongruent stimuli) which was significantly reduced when the composite faces were misaligned. An index of the composite face effect was calculated by subtracting the congruency effect in misaligned trials from the congruency effect in the aligned trials. Critically, the tDCS manipulation influenced this index of the composite effect in both active tDCS conditions by reducing it compared to sham (Yang et al 2014, Experiment 2). But Renzi et al (2014, Experiment 1), using a similar single-blind, within-subjects design targeting a closely related area, found that anodal tDCS delivered over occipital sites did not influence the behavioural composite face effect. Once again the results from the accuracy data revealed a significant congruency effect which was significantly reduced when the composite faces were misaligned (i.e., a composite face effect). But, unlike Yang et al (2014, Experiment 2) no effect of stimulation on this result was found.

No study has yet investigated the effects of tDCS applied at Fp3 on the composite face effect. This phenomenon serves the aim of our investigation because it allows us for the first time, to test the effects of tDCS on upright faces without the involvement of the inverted faces. On the one hand, in agreement with our perceptual learning account and the previous work conducted using the same tDCS procedure on the inversion effect we would expect overall performance across all the composite face conditions to be reduced because all the stimuli presented are upright faces that participants had never seen before entering the lab. This prediction is based on the fact that our tDCS procedure would maintain the salience of the common elements shared among all the upright faces at a relatively high level. Thus, it would harder for the participants to learn about the unique elements typical of each face causing more difficulty at detecting whether the “target” face is same or different from the “test” face despite the task being easier than the usual old/new recognition task used in previous work (Civile, Verbruggen et al., 2016; Civile et al., 2018; Civile et al., 2019; and Civile et al., 2020). If confirmed, these results would provide further evidence in support of this tDCS procedure being able to influence our life expertise in being exposed to upright faces manifested as perceptual learning. On the other hand, we would explore how tDCS would affect the size of the composite face effect in its own right. Given the relatively few studies investigating expertise in the composite face effect, here we provide an alternative and convergent approach using our tDCS procedure which has been demonstrated to be able to modulate perceptual learning in the context of face processing. Because this is the first study testing the effects of tDCS delivered at Fp3 on the composite face effect, there is no previous evidence suggesting whether or not the reduction in overall performance (predicted by our perceptual learning account) would also modulate the composite effect. One could predict that if all the composite faces are equally affected by the tDCS procedure, then they would all suffer a similar decrement in performance which would result in no effect on the size of the composite effect. However, alignment or misalignment might influence whether the composite stimuli are experienced as a whole or as two disparate halves and with the conflicting findings (see Renzi et al., 2014; and Yang et al., 2014) on the tDCS influence on the composite face effect, it would be hard to predict the results. We then reserve this part to the more exploratory part of the work here reported.

In **Experiment 1a**, we delivered anodal tDCS at Fp3 site and sham as a control (between-subjects) while subjects performed a face-matching task. Unlike the face inversion effect, the composite face effect is difficult to assess using old vs new recognition task, thus a matching task is usually employed to assess performance, wherein participants are presented with two composite arrangements sequentially and are asked to judge whether the target stimuli are identical or not (Goffaux & Rossion, 2006; Le Grand et al., 2004). The composite faces were created by using the top and bottom halves from two different faces.

In a complementary fashion, **Experiment 1b** aimed to extend our basic tDCS-induced effects on the inversion effect to a face-matching task paradigm. Previous studies adopted a face-matching task to study the face inversion effect specifically testing individuals with face recognition impairments (e.g. prosopagnosia). This because the task is easier to perform, ensuring a higher level of performance that otherwise would not be obtained using the old/new recognition task traditionally adopted to test the inversion effect (Farah et al., 1995; Busigny & Rossion, 2010). However, no study has yet looked at the effects of tDCS at Fp3 on the face inversion effect using a face-matching task.

Importantly, in **Experiment 2** we attempted to replicate Experiment 1a, as well as investigating the effects of anodal tDCS stimulation delivered at occipital site (P08 based on a 20-channel EEG cap) on the composite face effect.

Experiments 1a & 1b

Method

Subjects

In total, 96 naïve (right-handed) subjects (19 male, 77 Female; Mean age = 20.3 years, age range= 18-25) took part in the two experiments. **Experiment 1a** and **Experiment**

1b each included 48 subjects randomly assigned to either sham or anodal tDCS groups (24 in each group). The sample size was decided based on previous studies that used the same tDCS experimental procedure (double-blind, between subjects) and montage to modulate perceptual learning and face recognition (Civile et al., 2018; Civile et al., 2019; Civile et al., 2020). 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 tDCS Paradigm

In both experiments we adopted the same tDCS paradigm previously used by Civile, Verbruggen et al (2016), Civile et al (2018), Civile et al (2019) and Civile et al (2020) to examine the modulation of perceptual learning and face recognition skills. The stimulation was delivered by a battery-driven constant current stimulator (neuroConn DC- Stimulator Plus) using a pair of surface sponge electrodes (7cm x 5cm i.e.35 cm^2) soaked in saline solution and applied to the scalp at the target areas for stimulation. We used a bilateral bipolar-non-balanced montage with one of the electrodes (anode) placed over the target stimulation area (Fp3) and the other (cathode) on the forehead over the reference area (right eyebrow). In agreement with the previous studies that have adopted the same Fp3 montage, once we had identified Cz we measured 7 cm anterior relative to the Cz and 9 cm to the left. Both experiments were conducted using a double-blind procedure reliant on the neuroConn study mode in which the experimenter inputs numerical codes (provided by another experimenter), that switch the stimulation mode between “normal” (i.e. anodal) and “sham” stimulation. In the anodal condition, direct current stimulation of 1.5mA intensity (current density: 0.043 mA/cm2) was delivered for 10 mins (5s fade-in and 5s fade out) starting as soon as the behavioral task began and continuing throughout the study. In the sham group, participants experienced the same 5s fade-in and 5s fade-out, but with the stimulation intensity of 1.5 mA delivered for just 30s, following which a small current pulse was delivered every 550ms (0.1mA over 15ms) for the remainder of the 10 minutes to check impedance levels.

Materials and the Behavioural Task

We used a set of 256 face images standardized to grayscale on a black background (Civile et al., 2011; Civile et al., 2018; Civile, Elchlepp., et al. 2018; Civile et al., 2019; Civile et al., 2020) and cropped to a standardized oval shape, removing distracting features such as the hairline, and adjusted to standardize image luminance. 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 Superlab 4.0.7b. on an iMac computer. Participants sat about 70 cm away from the screen on which the images were presented. Importantly, in **Experiment 1a**, we used this set of face images to construct the composite faces. Both experiments included a "Training phase" and a "Test phase". The training phase was the same in both experiments.

Training phase. Once subjects gave their consent, the instructions for the training phase were presented on the screen. The aim of the task was for the subjects to associate the correct response keys 'X' or '.' with the words SAME or DIFFERENT according to the allocated counterbalance condition. Overall, 48 trials (24 Same and 24 Different) were presented one at a time in random order for <1s alternated with a fixation cue presented for 1s. Subjects were encouraged to press either the 'X' key or '.'as quickly as possible to classify the words SAME or DIFFERENT. Hence, they received a feedback message after each of their response whether it was correct or incorrect. Following this, subjects were presented with the instructions pertaining to the face-matching experimental task.

Test phase Experiment 1a. Subjects were engaged in a *same/different* task over 128 trials. Each trial began with a fixation cue presented in the centre of the screen (1s), followed by a TARGET face stimulus (1s), an interstimulus interval (1.5s) and a TEST face stimulus (≤2s). They pressed either the 'X' key or '.'as quickly as possible to classify the test face as "same" or "different" to the target face. All faces were presented upright and included four different conditions created by crossing two factors (congruent/incongruent x aligned/misaligned). The first (TARGET) and second (TEST) faces of a trial were always both either aligned or misaligned. Congruent and incongruent trials were presented in a counterbalanced fashion with aligned and misaligned stimuli randomly intermixed. The response keys were counterbalanced across participants and corresponded to the same keys used in the training phase for that participant. Participants were instructed to respond only to the top half of the TEST face, they had to judge whether it was the "same" or "different" as the top half of the TARGET face. In agreement with previous studies we adopted the full experimental design (Richler et al., 2011; Richler, Mack et al., 2011; Yang et al., 2014; Renzi et al., 2014; Murphy et al., 2017). In *Congruent Aligned* trials, participants first saw a TARGET face composite created by selecting the top and bottom halves of two different faces (e.g. A+B, where A is the top half and B the bottom half) and placing one above the other. Following this, in the TEST face trial the participants would either see the same TARGET face composite (A+B) or a new face composite created by selecting the top and bottom halves of two different faces (e.g. C+D). The *Incongruent Aligned* trials differed from the Congruent Aligned ones in the relationship of the TEST faces to the TARGET faces; they were presented either with the "same" top halves as for the TARGET faces but with different bottom halves (A+D), or with "different" top halves from the TARGET faces but the same bottom halves (C+B). Taking into account that the participants had never seen the original faces from which the various halves were selected from, Aligned stimuli could be considered as "regular" upright faces. In *Congruent* and *Incongruent Misaligned* trials the top and bottom halves of each composite were shifted horizontally relative to one another (one to the left and one to the right side) so that they overlapped across half their length (Figure 2).

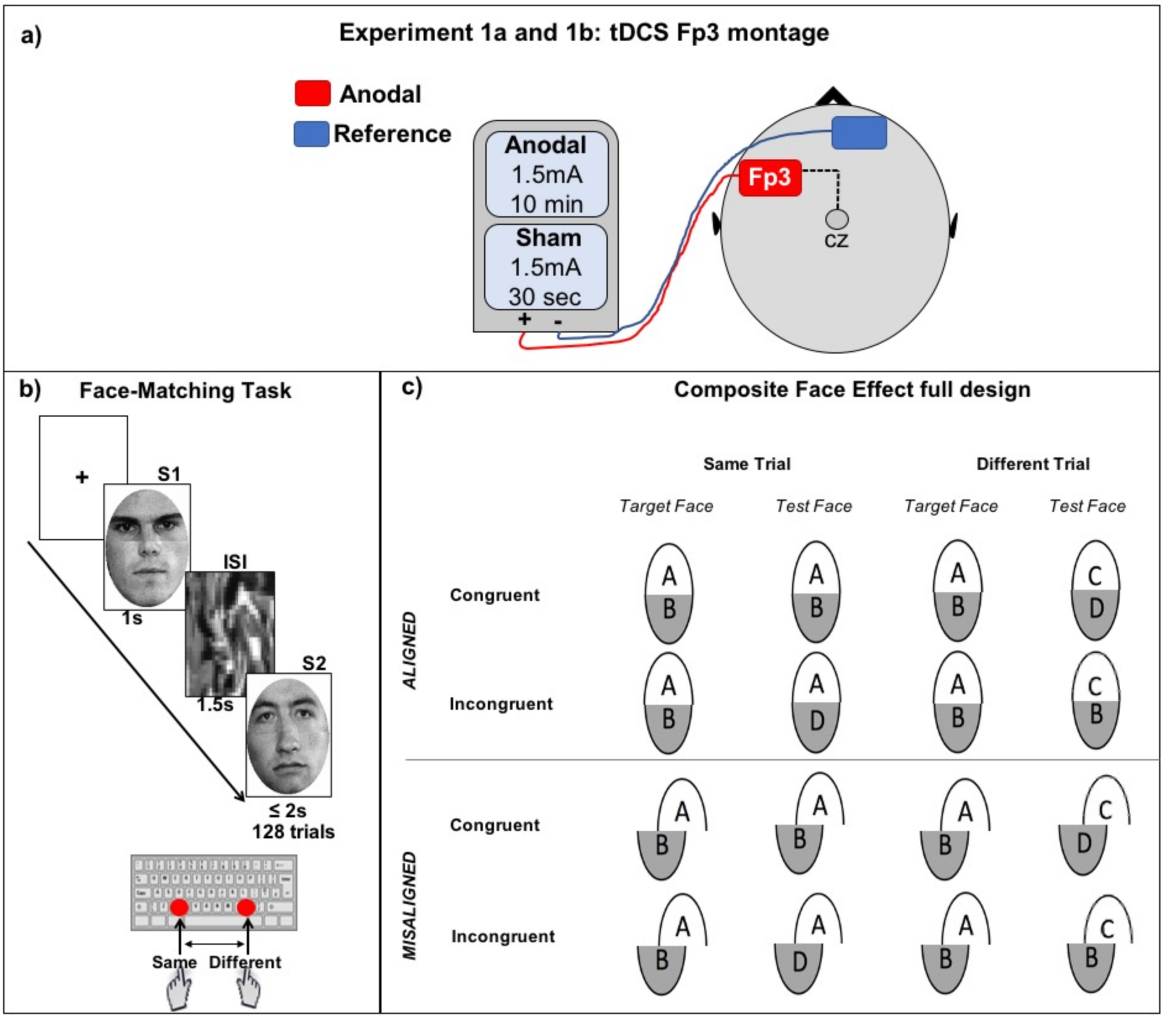

Figure 2. *Panel a* illustrates the tDCS Fp3 montage adopted in Experiment 1a and 1b. *Panel b* is a schematic representation of the Face-Matching task and composite faces adopted in the Experiment 1a. In Experiment 1b the same Face-Matching task was used but with regular faces shown upright and inverted. *Panel c* illustrates the complete design of the composite face effect. In each face pair, the first composite is the target, and the second composite is the test face. Participants attend to the top half (white color) and neglect the irrelevant bottom half (gray color). In the congruent condition, the target and the test face halves (top and bottom) are either both the *same* or are both *different*. In the incongruent condition, the

bottom halves of the target and test faces have the opposite relationship to that in the top halves. In the misaligned conditions the top and bottom halves of each composite are translated horizontally relative to one another.

Test Phase Experiment 1b. In this case as well, subjects were engaged in a *same/different* task over 128 trials (64 upright and 64 inverted). Each trial began with a fixation cue presented in the centre of the screen (1s), followed by a TARGET face stimulus (1s), an interstimulus interval (1.5s) and a TEST face stimulus (≤2s). Subjects pressed either the 'X' key or '.' key as quickly as possible to classify the test face as "same" or "different" to the target face. The first and second faces of a trial were always in the same orientation, and upright and inverted trials were randomly intermixed. The response keys were counterbalanced across subjects and corresponded to the same keys used in the training phase.

Results

Data Analysis

In the three experiments reported here, the accuracy data from all the participants in a given experimental condition was used to compute a *d′* sensitivity measure (Stanislaw & Todorov, 1999) for the face-matching task (same and different stimuli for each stimulus type) where a *d′* of 0 indicates chance-level performance. Hence for Experiments 1a and 2 we computed separate *d'* scores for congruent-aligned, congruent-misaligned, incongruent-aligned, and incongruent-misaligned stimuli. In Experiment 1b we computed *d'* scores for upright and inverted face stimuli. To calculate *d′*, we used subjects' hit rate (H), the proportion of *same* trials to which the participant responded *same*, and false alarm rate (F), the proportion of *different* trials to which the participant responded *same*. Intuitively, the best performance would maximize H (and thus minimize the Miss rate) and minimize F (and thus maximize the Correct Rejection rate); and thus, the larger the difference between H and

F, the better is the subject's sensitivity. However, d'' is not simply H – F; rather, it is the difference between the z transforms of these two rates: d' = z(H) – z(F) where neither H nor F can be 0 or 1 (if so, then they are adjusted slightly up or down). When either H or F were 0 these were increased by 1 divided by double the number of trials in each stimulus condition. When either H or F were 1 these were decreased by the same amount.

In all three experiments we assessed performance against chance to show that stimulus' conditions in both the tDCS sham and anodal groups were significantly above chance (For all conditions we found $p < .001$ for this analysis). Each p-value reported for the comparisons between conditions is two-tailed, and we also report the F or t value along with effect size (η^2_p). We analyzed the reaction time (RT) data to check for any speed-accuracy trade-off. We do not report these analyses because they do not add anything to the interpretation of the results. For completeness, we have also analysed the data from the raw accuracy scores corresponding to *same* and *different* trials in each experiment. We report those analyses in the Supplemental Material file (Part A).

Experiment 1a

As shown in Figure 3, Panel a, the results from the data analysed here demonstrate that we can obtain the basic composite effect and that our tDCS procedure does not influence it. Importantly, Panel b shows that anodal tDCS was affecting overall performance vs sham as predicted.

We computed a 2 x 2 x 2 mixed model design using, as within-subjects factors, *Congruency* (congruent or incongruent), *Alignment* (aligned or misaligned), and the between-subjects factor *tDCS Stimulation* (sham or anodal). Analysis of Variance (ANOVA) revealed a highly significant main effect of *Congruency*, $F(1, 46) = 356.61$, $MSE = 64.93$, $p < .001$, $\eta^2_p = .88$, which indicated that congruent trials were better responded to than incongruent trials, and no significant main effect of *Alignment*, $F(1, 46) = .584$, $MSE = 0.88$, $p = .45$, $\eta^2_p = .01$.

A significant interaction was found between *Congruency* and *Alignment,* $F(1, 46) = 15.02$, $MSE = 2.41$, $p < .001$, $\eta^2_p = .25$, due to the advantage for congruent over incongruent trials being greater when the two halves of the face were aligned ($M = 1.39$, $SD = .57$), $t(47) = 16.60$, $p < .001$, $\eta^2_p = .85$, compared to when they were misaligned ($M = 0.93$, $SD = .58$), $t(47) = 11.04$, $p < .001$, $\eta^2_p = .72$ (this interaction is the conventional measure of the composite face effect). We found no significant interaction between the factors *tDCS Stimulation* and *Congruency,* $F(1, 46) = 1.18$, $MSE = 0.21$, $p = .28$, $\eta^2_p = .02$, nor between *tDCS Stimulation* and *Alignment*, $F(1, 46) = .120$, $MSE = 0.01$, $p = .73$, $\eta^2_p < .01$. There was also no significant three-way interaction between our factors, $F(1, 46) = .341$, $MSE = 0.05$, $p = .56$, $\eta^2_p < .01$, indicating that our neurostimulation did not significantly influence the composite face effect. Importantly, we did find a significant main effect of the between-subjects factor *tDCS Stimulation*, $F(1, 46) = 5.02$, $MSE = 5.44$, $p = .030$, $\eta^2_p = .10$, indicating that anodal stimulation had significantly reduced overall performance for upright faces ($M = 2.34$, $SD = .55$) averaged across all conditions (congruent/incongruent aligned/misaligned) compared to sham ($M = 2.68$, $SD = .48$, see Figure 3).

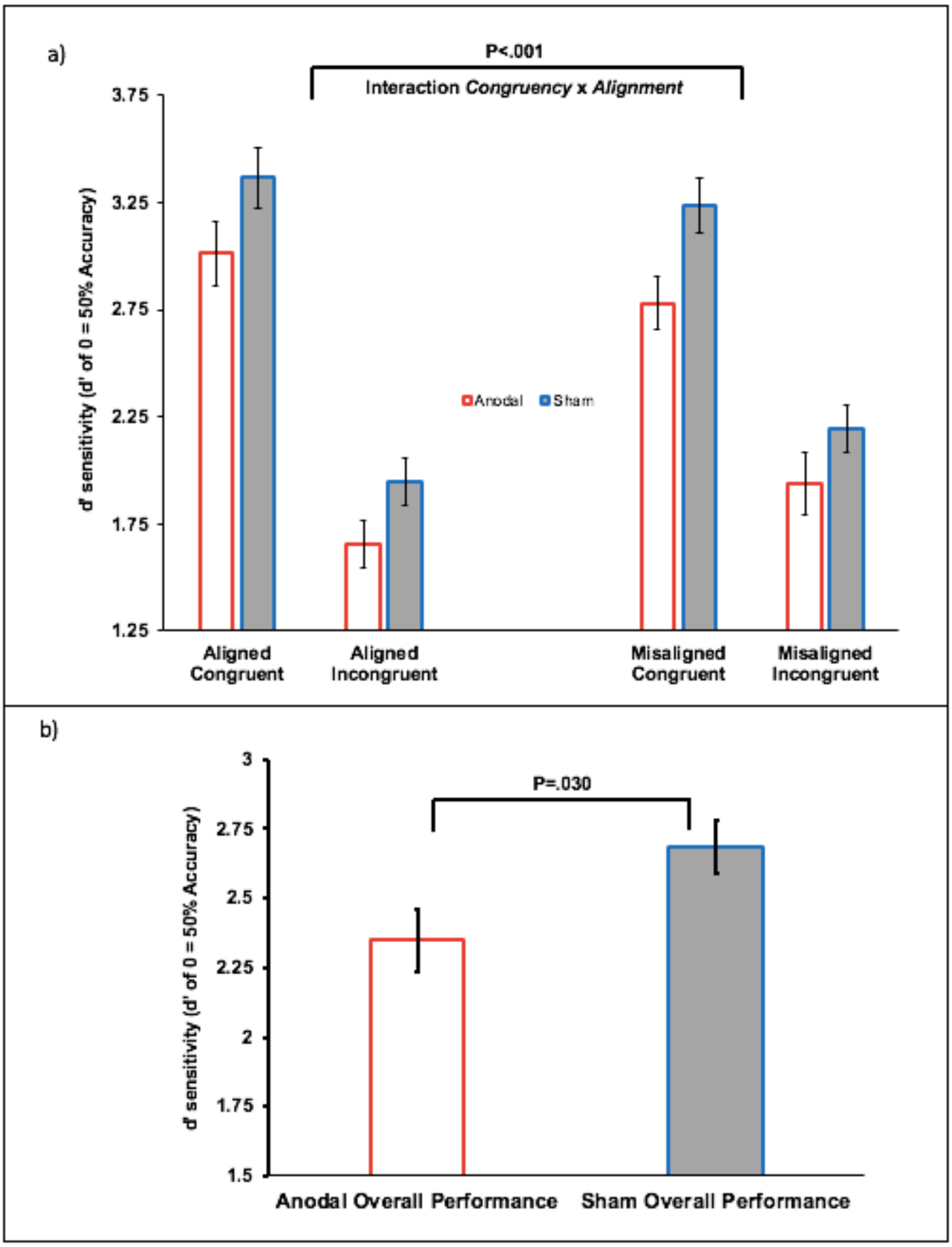

Figure 3 reports the results from Experiment 1a. The *x*-axis shows the stimulus conditions, the *y*-axis shows d'. Error bars represent s.e.m. *Panel a* shows the results for the interaction between the factors *Congruency* and *Alignment*. This is the conventional measure of the composite effect. It can be seen that performance for congruent stimuli was better than that for incongruent stimuli in the aligned stimuli, and this difference was significantly reduced when the stimuli were misaligned. No differences were found between the tDCS

groups. *Panel b* shows the significant effect of anodal stimulation relative to sham on overall performance.

Experiment 1b

As depicted in Figure 4, the results from this experiment show a reduced face inversion effect in the anodal condition compared to that found in the sham group.

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). Analysis of Variance (ANOVA) revealed a significant main effect of *Orientation* $F(1, 46) = 32.22$, $MSE = 6.30$, $p < .001$, $\eta^2_p = .41$, which simply confirmed that upright faces were better responded to than inverted ones overall. There was a marginally significant two-way interaction between Orientation and Stimulation, $F(1, 46) = 3.71$, $MSE = 0.72$, $p = .060$, $\eta^2_p = .07$. As in Civile et al (2018), Civile et al (2019), and Civile et al (2020), no main effect of *tDCS Stimulation* was found supporting the fact that the tDCS does not simply reduce overall performance, $F(1, 46) = .300$, $MSE = 0.23$, $p = .58$, $\eta^2_p < .01$.

Follow-up 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 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. A significant inversion effect was found in the sham group, $t(23) = 5.21$, $p < .001$, $\eta^2_p = .54$ ($M = 0.69$, $SD = .64$), and also in the tDCS anodal group (although smaller, $M = 0.34$, $SD = .60$), $t(23) = 2.72$, $p = .012$, $\eta^2_p = .24$. Performance for upright face stimuli in the anodal group was numerically lower compared to that in the sham group, $t(46) = 1.45$, $p = .15$, $\eta^2_p = .06$.

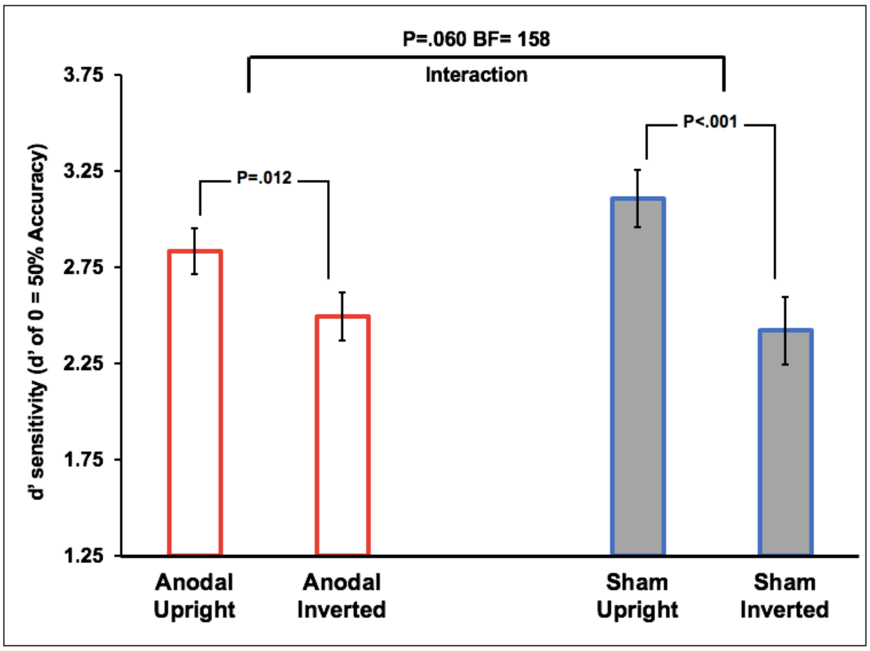

Figure 4 reports the results from Experiment 1b. The *x*-axis shows the stimulus conditions. The *y*-axis shows sensitivity d' measure. Error bars represent s.e.m.

Bayes Factor Analyses for Experiment 1b

At this point we should ask whether the results for the face inversion effect we have obtained using our tDCS procedure with a face matching task are commensurate with those we have obtained in the past using an old/new recognition paradigm. Using the procedure outlined by Dienes (2011), we conducted a Bayes analysis for the difference between the d' values for upright and inverted stimuli (i.e. the inversion effect score) and compared the sham and anodal groups (i.e. capturing the 2 x 2 interaction) in Experiment 1b. We used as the *priors* the differences found in Civile et al (2018 Experiment 1 and 2), Civile et al (2019), and Civile et al (2020 Experiment 3a) averaged together, setting the standard deviation of p (population value | theory) to the mean for the difference between the inversion effect in sham group vs that in the anodal group (0.35). We used the standard error (0.10) and mean difference (0.35) between the inversion effect in the sham group vs that in the anodal group in Experiment 1b. We assumed a one-tailed distribution for our theory and a mean of 0. This gave a Bayes factor of 158, which is very strong evidence (because it is much greater than 10, for the conventional cut-offs see Jeffrey, 1961) that these results are in line with what we would expect based on previous work i.e. that tDCS reduces the inversion effect with faces.

Similarly, in order to follow up previous work where performance for the upright faces was better in the sham group compared to that in the anodal group, we also calculated the Bayes factor for this effect using as priors the mean difference between sham upright faces and anodal upright faces found in Civile et al (2018 Experiment 1 and 2), Civile et al (2019), and Civile et al (2020 Experiment 3a), averaged together (0.23). We then used the standard error (0.15) and mean difference (0.27) between sham upright faces and anodal upright faces in Experiment 1b. Once again, we assumed a one-tailed distribution for our theory and a mean of 0. This gave a Bayes factor of 3.18, which is good evidence (as greater than 3) for the position that performance to upright faces is reduced by tDCS, and consistent with our previous results.

Discussion

Our results from this experiment are very straightforward. In **Experiment 1a** we find that the tDCS procedure we employ that has proven so reliable in reducing the face inversion effect over a number of experiments (and has done so in **Experiment 1b** of this paper) has failed to have any impact on the composite face effect, even though we have been able to demonstrate that effect by means of our significant Congruency by Alignment interaction. At the same time, the one effect that we could predict for Experiment 1a based on our previous work, that performance to upright faces would be reduced by this tDCS procedure, has been confirmed by the significant main effect of the *tDCS Stimulation* factor. Thus, we can have confidence that our paradigm is suitable for demonstrating the composite face effect, and that our tDCS procedure is working. Experiment 1b simply confirms that it is possible to get our basic effect, a reduction in the inversion effect, with a face matching paradigm. It also confirms the effect on upright faces. Clearly our results in Experiment 1b are much as would be predicted from previous work (Civile et al., 2018; Civile et al., 2019; Civile et al., 2020). Given this, our focus will now be on the reliability of the results of Experiment 1a.

Experiment 2 attempts to replicate the findings in Experiment 1a. Importantly, in addition to the anodal and sham groups, Experiment 2 also included an additional active stimulation group targeting occipital areas (P08 based on a 20-channel EEG cap). We selected the P08 area for the stimulation based on previous studies that found the N170 ERP component and its modulation in response to regular or distorted faces (e.g. scrambled, Thatcherised) and to prototype-defined categories of objects (e.g. checkerboards) to be the largest on this specific channel (Rossion & Jacques, 2008; Civile, Elchlepp et al., 2018; Civile, Zhao et al., 2014 Experiment 4; Civile et al., 2012a,b). It is also the approximate stimulation site used by the two studies just reviewed. Both Yang et al (2014, Experiment 2) and Renzi et al (2014, Experiment 1) showed no main effect of tDCS on overall performance. Hence, we expected to find no main effect of tDCS delivered at P08 on overall performance, thus, acting as an *active control* for tDCS delivered at Fp3, which we predict will influence perceptual learning and hence reduce overall performance as in Experiment 1a. Finally, whereas Yang et al (2014, Experiment 2) found that tDCS did affect the composite face effect, Renzi et al (2014, Experiment 1) found no effect of tDCS on the composite face effect. By using a double-blind and between-subjects procedure, we aimed to establish whether tDCS delivered at P08 would affect the composite face effect.

Experiment 2

Method

Subjects

In total, 72 naïve (right-handed) subjects (29 male, 43 Female; Mean age = 21 years, age range= 18-27) took part in the two experiments. Subjects were randomly assigned to either sham or anodal Fp3 or anodal P08 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 tDCS Paradigm

For the Fp3 montage we adopted the same procedure as for Experiment 1a and 1b. For the P08 montage (*active control*) we used a 10-20 EEG system cap to individuate the specific location on each participant (Figure 5). In both the anodal conditions (Fp3, P08) direct current stimulation of 1.5mA was delivered for 10 mins (5s fade-in and 5s fade out) starting as soon as the behavioral task began and continuing throughout the study. In the sham group, participants experienced the same 5s fade-in and 5s fade-out, but with the stimulation intensity of 1.5 mA delivered for just 30s, following which a small current pulse was delivered every 550ms (0.1mA over 15ms) for the remainder of the 10 minutes to check impedance levels. Importantly, to ensure the double-blind feature of the active vs sham stimulation, in the sham group half of the participants received sham tDCS under the Fp3 montage and the other half under the P08 montage.

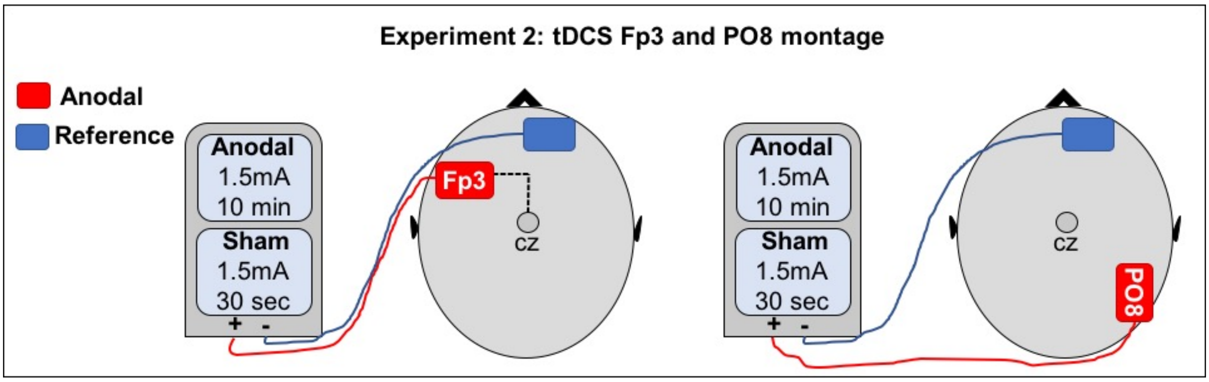

Figure 5 illustrates the tDCS montages used in Experiment 2. In total 72 participants were recruited and randomly assigned to either sham (12 Fp3 and 12 P08) or anodal Fp3 or anodal P08 tDCS groups (24 in each).

Materials and the Behavioural Task

The same stimuli, composite effect design, and Face-Matching task as for Experiment 1a.

Results

As represented in Figure 6, Panel a, the data confirmed the basic composite effect and show no differences on this effect between the tDCS conditions (sham, anodal Fp3, anodal PO8). Importantly, Panel b shows that anodal tDCS reduced overall performance compared to sham and compared to anodal stimulation at PO8 (which in this case functions as an active control).

We computed a 2 x 2 x 3 mixed model design using, as within-subjects factors, *Congruency* (congruent or incongruent), *Alignment* (aligned or misaligned), and the between-subjects factor *tDCS Stimulation* (sham, anodal Fp3, or anodal PO8). Analysis of Variance revealed a significant main effect of *Congruency*, $F(1, 69) = 214.26$, $MSE = 86.86$, $p < .001$, $\eta^2_p = .75$, which indicated that congruent trials were better responded to than incongruent trials, and no significant main effect of *Alignment*, $F(1, 69) = .011$, $MSE = 0.07$, $p = .78$, $\eta^2_p < .01$. In line with Experiment 1a, here as well we find a significant interaction between *Congruency* and *Alignment,* $F(1, 69) = 24.33$, $MSE = 4.20$, $p < .001$, $\eta^2_p = .26$, due to the advantage for congruent over incongruent trials being greater when the two halves of the face were aligned ($M = 1.34$, $SD = .74$), $t(71) = 15.39$, $p < .001$, $\eta^2_p = .77$, compared to when they were misaligned ($M = .85$, $SD = .76$), $t(71) = 9.47$, $p < .001$, $\eta^2_p = .59$. We have thus replicated the composite face effect found in Experiment 1a. We found no significant interaction between the factors *tDCS Stimulation* and *Congruency,* $F(1, 69) = .336$, $MSE = 0.13$, $p = .71$, $\eta^2_p < .01$, nor between *tDCS Stimulation* and *Alignment*, $F(1, 69) = 1.29$, $MSE = 0.19$, $p = .28$, $\eta^2_p = .03$. There was also no significant three-way interaction between our factors, $F(1, 69) = .345$, $MSE = 0.06$, $p = .71$, $\eta^2_p < .01$. Importantly, as for Experiment 1a, we found a significant main effect of the between-subjects factor *tDCS Stimulation*, $F(1, 69) = 4.07$, $MSE = 8.56$, $p = .021$, $\eta^2_p = .10$. An independent sample t-test revealed that anodal stimulation at Fp3 significantly reduced overall performance ($M = 1.94$, $SD = .97$) averaged across all conditions (congruent/incongruent aligned/misaligned) compared to sham (*M* = 2.44, *SD* = .61), $t(46) = 2.10$, $p = .041$, $\eta^2_p = .09$. Overall performance in the anodal Fp3 group was also significantly reduced compared to that in the anodal PO8 group (*M* = 2.48, *SD* = .49), $t(46) = 2.39$, $p = .020$, $\eta^2_p = .11$. No difference was found between the anodal PO8 vs sham group, $t(46) = .247$, $p = .80$, $\eta^2_p < .01$ (Figure 6).

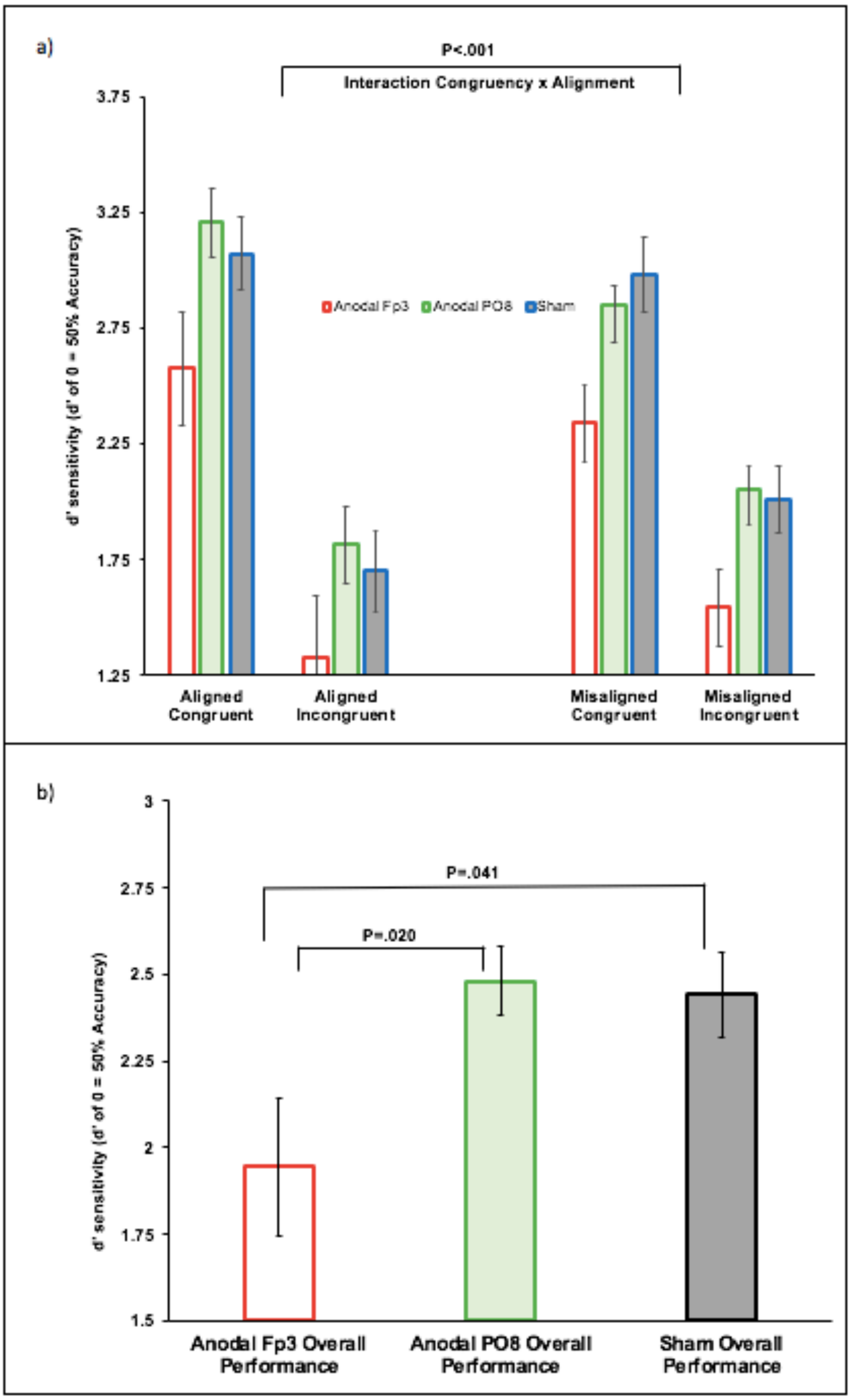

Figure 6 reports the results from Experiment 2. The *x*-axis shows the stimulus conditions. The *y*-axis shows d'. Error bars represent s.e.m. *Panel a* gives the results for the conventional measure of the composite effect. Congruent stimuli were better responded than incongruent stimuli, but this difference was significantly reduced when the stimuli were misaligned. *Panel b* shows the effects of anodal Fp3, PO8 and sham tDCS on overall performance.

Discussion

The results of Experiment 2 replicate and extend those of Experiment 1a. Once again, we have a significant composite face effect, but no detectable effect of stimulation on it (as demonstrated by the non-significant interactions involving the Stimulation factor). And we also have an effect of Fp3 stimulation on overall performance. But this time we have a little more, because we are able to say that Fp3 stimulation reduced performance to upright faces relative both to Sham (replicating Experiment 1a) and to P08 (an active control). We now further assess the quality of the evidence for both the null result on the composite face effect and the effect of Fp3 stimulation on overall performance using a Bayesian analysis.

Bayes Factor Analyses Experiments 1a and 2

We first calculated the Bayes factor for the null effect of tDCS at Fp3 on the composite face effect. Based on our hypothesis that tDCS at Fp3 disrupts perceptual learning then, if perceptual learning was contributing in some way to the composite face effect, this would reduce that effect, so clearly a one-tailed approach is called for. We then asked what priors would be best for this analysis, and the obvious answer is simply to use the Sham data from each experiment to generate these. Taking this approach, the mean effect in Experiment 1a is .381 and we halved this to give .191. We then used this value as the standard deviation of p (population value | theory). The reason for doing this is that the plausible maximum is supposed to be twice this value, and that would correspond to the entire composite face effect being eliminated in the Fp3 condition in this analysis. We set the mean of p (population value

| theory) to 0 and used the standard error (0.16) and mean difference (-0.135) between the composite effect in the sham group and the anodal group for Experiment 1a as our sample standard error and mean. This technique should give a large Bayes factor if the difference between Sham and Anodal Fp3 conditions is large (i.e. the stimulation had reduced the composite face effect), and a small Bayes factor if this difference was small and stimulation did not affect the composite effect (i.e. the null). It gave a Bayes factor of 0.41, which on its own does not quite meet the criterion for persuasive evidence for the null (criterion is less than 0.3). We repeated this process for Experiment 2 using the mean difference (-.046) and standard error (.17) for that sample and the Sham composite effect of .404 (giving an SD of .202) which resulted in a Bayes factor for this experiment of 0.55. Combining these Bayes factors by multiplying them gives an overall Bayes factor of 0.23 based on all the evidence we have available, which is less than 0.3. and hence can be considered as good evidence for the null, supporting the claim that the composite effect in both Sham and Fp3 conditions are drawn from the same distribution.

We then conducted a Bayes analysis for the difference between the overall performance score (average of all stimulus' conditions congruent/incongruent aligned/misaligned) in the sham and in the anodal Fp3 groups in Experiment 2, using as *priors* the differences found in Experiment 1a, setting the standard deviation of p (population value | theory) to the mean for the difference between the overall performance in the sham group vs that in the anodal group (0.34). We used the standard error (0.17) and mean difference (0.50) between the overall performance in the sham group vs that in the anodal group in Experiment 2. We assumed a one-tailed distribution for our theory and a mean of 0. This gave a Bayes factor of 28.28, which is strong evidence that these results are in line with what we would expect based on Experiment 1a. It would seem then that the overall reduction in performance to upright faces observed with our face matching task in the context of a composite face paradigm in Experiments 1a and 2 is reliable.

General Discussion

We set out in this paper to first summarise and then further investigate the effects of our tDCS procedure on face recognition skills, particularly our expertise for upright faces. One aim was to test the perceptual learning account that is the basis of our explanation for the tDCS-induced effects found by Civile, Verbruggen et al (2016) Civile et al (2018), Civile et al (2019) and Civile et al (2020). Those studies showed how anodal stimulation delivered over the Fp3 area for a short period of time can reduce both the inversion effect for prototype-defined familiar checkerboards and the robust inversion effect for faces. Critically, in both cases anodal tDCS disrupted performance for upright stimuli compared to sham. Here we predicted that the same tDCS procedure would significantly reduce overall performance compared to sham in our composite effect experiments using a matching task based on the fact that the specific paradigm involved employed only upright faces. What we found is very straightforward. There was the expected reduction in performance to the upright face stimuli contingent on tDCS in both Experiments 1a and 2. The additional Bayesian analysis confirms the reliability of these effects. Furthermore, Experiment 2 also provides evidence from an active control group showing that the reduction in overall performance cannot be obtained by targeting another brain area. These results confirm that when our particular tDCS procedure is applied to a task that involves only upright faces it impairs overall performance compared to sham (Experiments 1a & 2) or the active control (Experiment 2). This establishes the effects of tDCS on upright faces in the absence of any inverted faces, and provides further direct support to Civile, Verbruggen et al (2016), Civile et al (2018), Civile et al (2019), and Civile et al (2020)'s claim that the tDCS procedure reduces performance for upright faces in either an old/new recognition task or a Face-Matching task.

Equally important is the Bayesian analysis we provide for Experiments 1a and 2 that suggests the null effect of Fp3 stimulation on the composite face effect observed in those experiments is real. Our logic here is that if the composite face effect is based on perceptual learning (by analogy with our analysis for the inversion effect) then Fp3 stimulation should reduce that effect by disrupting perceptual learning. The maximum size of such an effect can plausibly be taken to be the actual size of the composite face effect, which gives the predicted size of the effect as half that. This is also in concordance with the analogy with the reduction in the inversion effect that we have observed in Experiment 1b using the same matching procedure. Here the reduction in the effect (0.35) is roughly half the size of the inversion effect in the sham group (0.69), so our use of half the effect size as the predicted effect of anodal tDCS at Fp3 for the composite face effect is in line with these data. The result of this analysis is good evidence for the null hypothesis, which in this instance amounts to a rejection of the idea that the composite face effect will show a similar reduction in size to the inversion effect consequential on Fp3 stimulation. Thus, we have good evidence for the claim that our technique affects some aspects of face processing, but not others. In particular, if we take the composite face illusion to be dependent on holistic processing of faces (and it is often used as a benchmark for assessing holistic processing), then we have evidence that our tDCS procedure does not affect this form of processing *per se*.

Experiment 1b, extends the effects of tDCS on the face inversion effect to a matching task rather than the study / test version of the old / new recognition task that we have used up to this point. This showcases the effects of tDCS on perceptual learning in an “easier” task that is often used to test individuals with face blindness (Farah et al., 1995; Busigny & Rossion, 2010). We note that the effects found in Experiment 1b are not quite as large as those we have usually found using an old/new recognition task. In regard to tDCS affecting the inversion effect compared to sham, the interaction showed a trend that was not significant on a two-tailed test. Furthermore, the effect of tDCS on the upright faces this time was not independently significant. Here, the additional Bayes factor analyses help us to frame our results within the context of previous studies, and show that these results are very much in line with those of previous studies and that the evidence for a reduction of the inversion effect due to worse performance on upright faces consequent on Fp3 stimulation is now overwhelming. But, we can speculate that perhaps the effects of tDCS on the inversion effect may have been impacted by the fact that we adopted a much easier task this time compared to that used in previous studies. This is corroborated by the fact that recognition performance for inverted faces is found to be high with this type of task, much higher than in our previous work. Future studies should replicate Experiment 1b, perhaps by varying the stimulus interval between the target face and the test face to see if that would make performance harder (this is a manipulation often used in the prosopagnosia face recognition literature).

We now interpret our main results in terms of the MKM theory of perceptual learning, drawing what general conclusions we can from the work reported in this paper and the work that led up to it. Our standard explanation of perceptual learning and its’ role in the inversion effect proceeds as follows. Under normal conditions, the MKM theory states that the salience of elements representing features of a stimulus that have strong associations with other elements that are also active at that time are reduced by a process of salience modulation based on prediction error. This has the effect of making the prototypical elements of an exemplar less salient and enhances the relative salience of elements unique to that exemplar improving its discriminability from other exemplars. This leads to the inversion effect reported in Civile, Zhao et al (2014), because the upright stimuli drawn from the familiar category benefit from this perceptual learning and are better discriminated as a consequence, increasing the difference in performance relative to inverted exemplars that do not benefit from this effect (because we are not familiar with inverted faces). Civile, Verbruggen et al (2016) Civile et al (2018), Civile et al (2019) and Civile et al (2020) interpreted the reduction of the inversion effect for checkerboards and faces, as being due to impaired recognition performance for upright stimuli based on the disruption of this modulation of salience. This followed from the anodal stimulation inducing, in effect, a reconfiguration of the mechanism for the development of 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 features common to those exemplars more prominent rather than exaggerating 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 and recognise different upright faces, which is normally enhanced by people's expertise for face processing acquired via experience and manifesting as perceptual learning.

These claims receive additional support here. Experiment 1b extends our basic effect of tDCS at Fp3 on the inversion effect to a different paradigm but does not in itself warrant much extra by way of discussion. We do note that once again the reduction in the inversion effect is partial and incomplete, implying that there is a component to the face inversion effect that we are not affecting and that may be due to other causes. The additional evidence in that experiment for this being due to an effect on upright faces is also in line with our previous results. But the results of Experiments 1a and 2 allow us to say more on this topic. Clearly, the effects of Fp3 stimulation are not in some way bound up with presenting both upright and inverted faces in our experiments to date. In the composite face effect experiments reported here only upright stimuli are used, but we still observe an independently significant reduction in overall performance relative to sham stimulation as a consequence of Fp3 stimulation, and we can also point to a significant difference between stimulation at Fp3 and P08 (i.e. the active control site). This latter result is our first demonstration under these conditions of an effect on upright faces using an active control and is noteworthy for that reason.

In addition to investigating the tDCS-induced effects on upright faces in Experiments 1a and 2 we also explored the effects of the tDCS procedure on the composite face effect itself. Both experiments show no modulation of the size of the composite face effect (the congruency effect in aligned trials minus the congruency effect in misaligned trials) by the tDCS active stimulation at either Fp3 or P08 compared to sham. This may suggest that the composite face effect does not have as its basis the same perceptual learning mechanisms that underpin at least one component of the inversion effect and that is why the tDCS at Fp3 did not affect it. In other words, the composite face effect may not be an expertise-based phenomenon in the sense we would apply this term to the face inversion effect. Given the analysis we provided earlier based on the MKM model that described how tDCS leads to reduced performance for upright faces, we can explain how it leads to a reduction in the face inversion effect and might not be expected to influence the composite face effect. If performance to upright faces is reduced, but performance to inverted faces is not (because these stimuli are essentially treated as novel stimuli as we have little experience of seeing faces inverted), then the inversion effect will be reduced. But, the composite face effect will suffer an equivalent decrement in performance for both congruent and incongruent faces (as both are upright), and so should not be affected. Alignment or misalignment might influence whether the composite is experienced as a whole or as two disparate halves but the implication of our results is that it is an orthogonal factor to the influence of tDCS in these circumstances.

Instead, the composite face effect may be better explained by the specificity account of face recognition, and, in particular, by an appeal to holistic processing of faces (Maurer et al., 2002). Whereas inverting a face would seem to affect all types of face processing including holistic processing (as it reduces the composite effect), the composite face effect would seem to be specifically linked to holistic processing. Several studies have applied different manipulations to composite faces with the aim of disrupting the spatial relations between features and have found that the composite face effect still occurred. For example, Hole, George and Dunsmore (1999) showed that a composite effect is found for upright faces (but not for inverted) even after constructing a photographic negative of the faces. The authors suggested that upright negative faces are sufficiently "face-like" to elicit holistic processing. According to this view, holistic processing is triggered by anything that roughly conforms to the basic plan of a face, and it establishes that it is a face that is being perceived, as opposed to any other kind of stimuli (e.g. an object). Thus, whereas sensitivity to first and second-order relations characterize both face and object recognition, holistic processing seems to be specific to faces. Speculatively, it may be possible to argue that if it is holistic processing that the tDCS delivered at Fp3 is not able to influence that is why, despite the inversion effect being significantly reduced (e.g. Civile et al., 2018; Civile et al., 2019; Civile et al., 2020), it is not entirely eliminated. In other words, the component of the face inversion effect that depends on holistic face processing is what remains after our tDCS manipulation.

Some additional evidence in support of this explanation was provided by Yang et al (2014, Experiment 2)'s study described earlier in the introduction. The authors targeted occipital-temporal brain areas which importantly are often considered to be vital in processing face stimuli specifically and showed that tDCS was able to modulate the composite face effect by reducing it compared to sham. No additional statistical analyses were provided to further investigate the basis for the reduced composite effect observed in this study, however, and a closer examination of Yang et al (2014 Experiment 2)'s results would seem to suggest that both active tDCS conditions reduced the composite effect by enhancing recognition performance for incongruent aligned face composites. This could suggest that whereas the tDCS delivered at Fp3 in the way used in the experiments reported here is influencing that component of face recognition due to perceptual learning mechanisms (as indexed by the inversion effect) and perhaps linked to sensitivity to first and second-order relations, tDCS delivered at occipital-temporal areas is affecting a component of face recognition related specifically to face stimuli (as indexed by the composite face effect). We speculate that Yang et al (2014 Experiment 2)'s technique may have disrupted holistic processing of the faces, allowing a more componential analysis that helped deal with incongruent aligned face composites by facilitating their being broken down into top and bottom halves.

However, one problem with this analysis is the results from our Experiment 2 active control group (P08) which is consistent with Renzi et al (2014 Experiment 1)'s findings. Both our Experiment 2 active control condition and Renzi et al (2014, Experiment 1)'s study showed no effects of tDCS delivered at occipital sites on the composite face effect. Interestingly, whereas our study and Renzi et al (2014 Experiment 1) adopted *d'* as a sensitivity measure (extracted from the accuracy) Yang et al (2014 Experiment 2) used instead a nonparametric sensitivity measure *A'* to analyze their results. To directly compare our results in Experiment 2 with those from Yang et al (2014 Experiment 2) we conducted some additional analyses based on *A'* (Stanislaw & Todorov, 1999; Verde, Macmillan & Rotello, 2006). The results are reported in the Supplemental Material file (Part B). Critically, the additional analyses using the *A'* measure revealed the same pattern of results as that shown for the *d'* measure. Hence, tDCS at Fp3 produces reduced overall performance indexed by *A'* compared to sham and tDCS at P08. No effect of tDCS active stimulation (either at Fp3 or P08) was found compared to sham on the composite face effect. Overall, in agreement with the results from our Experiment 2 and Renzi et al (2014 Experiment 1)'s study, tDCS delivered at occipital sites does not modulate the composite face effect, at least not in our hands. Given that Yang et al (2014 Experiment 2) found that tDCS delivered at occipital-temporal sites does modulate the size of the composite face effect, it is perhaps still too soon to draw any firm conclusions on this point, and future studies should further investigate this by perhaps systematically looking at the differences between stimulation at the P8 as used by Yang et al (2014 Experiment 2) and that used in our Experiment 2 (i.e. P08) which is similar to that adopted by Renzi et al (2014 Experiment 1). It is important to notice how closely located the P8 and P08 channels are and how with the sponge size usually adopted in tDCS studies (7cm x 5cm i.e.35 cm^2) it is not possible to avoid the sponge surface to cover both areas, although the location of the centre of the sponge would change depending on targeted area. It is also important for future studies to examine the effects of having the reference channel placed on the forehead vs a symmetrical bilateral location.

One may also suggest that instead of face specific perceptual processes other factors may contribute to influence the composite face effect and the inversion effect. In a recently published work, Liu et al (2020) tested the effects of task-relevant vs task-irrelevant characteristics on the composite face effect. Hence, in Experiment 1, a gender categorization task directed subjects to gender as the task-relevant information and race as the task-irrelevant information. In Experiment 2, a race categorization task made race the task-relevant information and gender the task-irrelevant information. The results from the two experiments revealed a larger composite face effect (i.e. slower responses to aligned vs misaligned incongruent stimuli) linked to task relevant information in particular when the subjects were asked to judge the bottom half of the composite faces (i.e. the relatively more difficult task). In contrast, the task-irrelevant information did not show a strong influence on the composite face effect in either experiment. The authors suggested that in addition to holistic processing, there is also top-down modulation of the targeted visual characteristics that can influence the composite face effect. Ratcliff et al (2011, Experiment 3) examined how top-down motives can guide perceptual processes and thus influence the composite face effect. A larger composite face effect was found when the stimuli presented were associated with high-status (e.g. CEO or doctor) compared to low-status (e.g. mechanic or plumber) occupational titles. In a similar vein, Civile, Colvin, Siddiqui and Obhi (2019) provided some evidence that modulation of top-down information can also influence the face inversion effect. Using an old/new recognition task involving a set of upright and inverted normal faces the authors found that the inversion effect was significantly reduced if the instructions at the beginning of the experiment (the study phase) indicated the faces to be of individuals with autism. As a control, a different group of subjects was presented with the same old/new recognition task involving the same faces but this time the instructions indicated the faces to be of regular people. Critically, in a further experiment the same authors showed that the inversion effect was re-established once that the subjects were provided with humanizing information as regards individuals diagnosed with autism. Interestingly, Hills et al (2019) showed the inversion effect was completely eliminated when the subjects believed they were being observed by the experimenter during the study. The authors suggested that social observation can cause the subjects to become somewhat anxious leading to reduced performance (especially for the upright faces) in a relatively difficult task (recognition of unfamiliar faces). Taken all together, these studies reveal how, in addition to the perceptual learning component of the inversion effect, and holistic processing in the composite effect, there may be a motivational or arousal component of face processing that can be influenced by social rather than lower-level perceptual processes. Future studies should aim to uncover the differences between these components.

In conclusion, our results further extend the findings reported by Civile, Verbruggen et al (2016) Civile et al (2018), Civile et al (2019) and Civile et al (2020), by establishing that tDCS anodal stimulation delivered at the DLPFC at Fp3 site impairs overall performance for upright faces compared to sham (Experiment 1a & 2) and compared to an active control site (Experiment 2) in a matching task, and that this can produce a reduction in the face inversion effect (Experiment 1b) but did not modulate the size of the composite face effect. Importantly, Experiment 2 reported in this paper is the first in the literature to systematically test the effects of tDCS applied at Fp3 on the composite face effect as well as further investigating the effects of stimulation at P08 on the same phenomenon. No effects of either active tDCS stimulation was found on the composite face effect.

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Supplemental Material for:

The Effects of transcranial Direct Current Stimulation on Perceptual Learning for Upright Faces and its Role in the Composite Face Effect.

Ciro Civile, Rossy McLaren, Fraser Milton, and I.P.L. McLaren

PART A: Additional Analyses on *same* / *different* trials

For completeness here we provide the additional statistical analyses of the accuracy scores for the *same* and *different* trials.

Experiment 1a. We computed a 2 x 2 x 2 x 2 mixed model design using, as within-subjects factors, *Congruency* (congruent or incongruent), *Alignment* (aligned or misaligned), *Trials* (same or different) and the between-subjects factor *tDCS Stimulation* (sham or anodal). Analysis of Variance (ANOVA) revealed a significant main effect of *Congruency*, $F(1, 46) = 539.58$, $p < .001$, $\eta^2_p = .92$, *Alignment*, $F(1, 46) = 14.02$, $p = .001$, $\eta^2_p = .23$, and *Trials*, $F(1, 46) = 168.63$, $p < .001$, $\eta^2_p = .78$. A significant interaction was found between *Congruency* and *Alignment,* $F(1, 46) = 33.46$, $p < .001$, $\eta^2_p = .42$ i.e. the composite face effect, and a significant three-way interaction *Congruency* x *Alignment x Trials,* $F(1, 46) = 35.62$, $p < .001$, $\eta^2_p = .43$. The composite effect was larger for the *same* trials compared to the *different* trials, $F(1, 46) = 36.61$, $p < .001$, $\eta^2_p = .44$. We found no significant interaction between the factors *tDCS Stimulation* and *Congruency,* $F(1, 46) = .016$, $p = .89$, $\eta^2_p < .01$, nor between *tDCS Stimulation* and *Alignment*, $F(1, 46) = .222$, $p = .63$, $\eta^2_p < .01$, nor between *tDCS Stimulation* and *Trials,* $F(1, 46) = 3.51$, $p = .071$, $\eta^2_p = .06$. There was also no significant three-way interaction between tDCS Stimulation x Congruency x Alignment, $F(1, 46) = .169$, $p = .68$, $\eta^2_p < .01$, confirming that the tDCS did not significantly influence the composite face effect. Furthermore, there was also no significant four-way interaction between all our factors, $F(1, 46) = .051$, $p = .82$, $\eta^2_p < .01$. Importantly, we did find a significant main effect of the between-subjects factor *tDCS Stimulation*, $F(1, 46) = 4.90$, $p = .032$, $\eta^2_p = .09$, confirming that anodal stimulation had significantly reduced overall performance for upright faces (M = 26.7, SD = 1.77) averaged across all conditions (congruent/incongruent aligned/misaligned) compared to sham (M = 29.6, SD = 1.87).

Experiment 1b. We computed a 2 x 2 x 2 mixed model design using, as a within-subjects factor, *Face Orientation* (upright or inverted), *Trials* (same or different), and the between-subjects factor *tDCS Stimulation* (sham or anodal). Analysis of Variance (ANOVA) revealed a significant main effect of *Orientation*, $F(1, 46) = 24.04$, $p < .001$, $\eta^2_p = .34$. There was no significant main effect of *Trials*, $F(1, 46) = .836$, $p = .36$, $\eta^2_p = .01$, nor a significant main effect of *tDCS Stimulation*, $F(1, 46) = .193$, $p = .66$, $\eta^2_p < .01$. No significant interaction between *Face Orientation* and *Trials* was found, $F(1, 46) = .387$, $p = .53$, $\eta^2_p < .01$. A trend towards a three-way interaction was found, $F(1, 46) = 3.736$, $p = .060$, $\eta^2_p = .07$. No significant interaction between *tDCS Stimulation* and *Trials*, $F(1, 46) = 3.527$, $p = .071$, $\eta^2_p = .06$, nor between *tDCS Stimulation* and *Inversion*, $F(1, 46) = 3.076$, $p = .086$, $\eta^2_p = .06$.

Stimulus Type		SAME		DIFFERENT	
		Upright Faces	**Inverted Faces**	**Upright Faces**	**Inverted Faces**
EXPERIMENT 1b	SHAM	M = 14.57 SD = 1.41	M = 14 SD = 1.39	M = 14.75 SD = 1.17	M = 13.37 SD = 2.33
	tDCS Fp3	M = 14.31 SD = 1.13	M = 13.64 SD = 1.95	M = 14.65 SD = 1.20	M = 14.5 SD = 0.94

Table 1. Mean accuracy scores for *same* and *different* trials in Experiment 1b.

Experiment 2. We computed a 2 x 2 x 2 x 3 mixed model design using, as within-subjects factors, *Congruency* (congruent or incongruent), *Alignment* (aligned or misaligned), *Trials* (same or different) and the between-subjects factor *tDCS Stimulation* (sham, anodal Fp3, or anodal PO8). Analysis of Variance (ANOVA) revealed a significant main effect of *Congruency*, $F(1, 69) = 338.93$, $p < .001$, $\eta^2_p = .83$, *Alignment*, $F(1, 69) = 7.82$, $p = .007$, $\eta^2_p =$

.10, and *Trials*, $F(1, 69) = 332.53$, $p <.001$, $\eta^2_p = .82$. A significant interaction was found between *Congruency* and *Alignment,* $F(1, 69) = 49.10$, $p < .001$, $\eta^2_p = .41$ i.e. the composite face effect, and a significant three-way interaction *Congruency* x *Alignment x Trials,* $F(1, 69) = 23.65$, $p < .001$, $\eta^2_p = .25$. The composite effect was larger for the *same* trials compared to the *different* trials, $F(1, 69) = 23.79$, $p < .001$, $\eta^2_p = .26$. We found no significant interaction between the factors *tDCS Stimulation* and *Congruency,* $F(1, 69) = .446$, $p = .64$, $\eta^2_p < .01$, nor between *tDCS Stimulation* and *Alignment*, $F(1, 69) = .901$, $p = .41$, $\eta^2_p = .02$, nor between *tDCS Stimulation* and *Trials,* $F(1, 69) = .090$, $p = .91$, $\eta^2_p < .01$. There was also no significant three-way interaction between tDCS Stimulation x Congruency x Alignment, $F(1, 69) < 01$, $p = 1$, $\eta^2_p < .01$, confirming that the tDCS did not significantly influence the composite face effect. Furthermore, there was also no significant four-way interaction between all our factors, $F(1, 69) = .962$, $p = .38$, $\eta^2_p = .02$. Importantly, we did find a significant main effect of the between-subjects factor *tDCS Stimulation*, $F(1, 69) = 4.77$, $p = .011$, $\eta^2_p = .12$. An independent sample t-test revealed that anodal stimulation at Fp3 significantly reduced overall performance ($M = 24.90$, $SD = 3.98$) averaged across all conditions (congruent/incongruent aligned/misaligned) compared to sham ($M = 26.86$, $SD = 2.19$), $t(46) = 2.11$, $p = .040$, $\eta^2_p = .09$. Overall performance in the anodal Fp3 group was also significantly reduced compared to that in the anodal PO8 group ($M = 27.19$, $SD = 1.53$), $t(46) = 2.62$, $p = .011$, $\eta^2_p = .13$. No difference was found between the anodal PO8 vs sham group, $t(46) = .590$, $p = .56$, $\eta^2_p < .01$.

Stimulus Type		SAME				DIFFERENT			
		Aligned Congruent	Aligned Incongruent	Misaligned Congruent	Misaligned Incongruent	Aligned Congruent	Aligned Incongruent	Misaligned Congruent	Misaligned Incongruent
EXPERIMENT 1a	SHAM	M = 30.33 SD = 1.43	M = 19.08 SD = 4.68	M = 30.12 SD = 1.77	M = 23.29 SD = 3.15	M = 30.08 SD = 2.12	M = 29.83 SD = 3.26	M = 29.83 SD = 1.71	M = 29.25 SD = 2.99
	tDCS Fp3	M = 29.29 SD = 2.17	M = 17 SD = 3.18	M = 28.54 SD = 2.44	M = 21.16 SD = 4.61	M = 29.45 SD = 2.12	M = 29.83 SD = 1.80	M = 29.08 SD = 2.24	M = 29.25 SD = 2.41
EXPERIMENT 2	SHAM	M = 29.08 SD = 2.79	M = 17.79 SD = 4.45	M = 28.33 SD = 4.20	M = 21.33 SD = 2.79	M = 29.95 SD = 1.94	M = 29.25 SD = 3.57	M = 29.83 SD = 1.83	M = 29.37 SD = 3.35
	tDCS Fp3	M = 26.83 SD = 4.89	M = 16.62 SD = 4.40	M = 26.12 SD = 6.51	M = 19.12 SD = 4.80	M = 28.29 SD = 4.21	M = 27.37 SD = 5.44	M = 27.25 SD = 4.46	M = 27.62 SD = 4.29
	tDCS P08	M = 29.33 SD = 2.82	M = 18.66 SD = 3.59	M = 28.54 SD = 2.65	M = 21.83 SD = 3.01	M = 30.20 SD = 1.58	M = 29.95 SD = 1.48	M = 29.33 SD = 2.20	M = 29.66 SD = 2.05

Table 2. Mean accuracy scores for *same* and *different* trials in Experiment 1a and 2.

PART B: Experiment 2 additional Analyses using *A'* Sensitivity Measure

To compare the results from our Experiment 2 vs those from by Yang et al (2014 Experiment 2) here we re-analyzed our data this time using the accuracy to extract a nonparametric measure of sensitivity *A'* computed using the formula illustrated in Yang et al (2014; see also Hsiao & Cottrell, 2009; Stanislaw & Todorov, 1999; Verde & Rotello, 2006). For correctness we conducted the same statistical analyses as for our Experiment 1b using *d'*. The analyses using *A'* showed the same pattern of results as those using *d'*.

We computed a 2 x 2 x 3 mixed model design using, as within-subjects factors, *Congruency* (congruent or incongruent), *Alignment* (aligned or misaligned), and the between-subjects factor *tDCS Stimulation* (sham or anodal Fp3 or anodal PO8). Analysis of Variance (ANOVA) revealed a significant main effect of *Congruency*, $F(1, 69) = 201.76$, $p < .001$, $\eta^2_p = .74$, and no significant main effect of *Alignment*, $F(1, 69) = 2.78$, $p = .11$, $\eta^2_p = .03$. Here as well we find a significant interaction between *Congruency* and *Alignment*, $F(1, 69) = 37.39$, $p < .001$, $\eta^2_p = .35$, due to the advantage for congruent over incongruent trials being greater when the two halves of the face were aligned, $t(71) = 14.15$, $p < .001$, $\eta^2_p = .74$, compared to when they were misaligned, $t(71) = 9.67$, $p < .001$, $\eta^2_p = .57$. We found no significant interaction between the factors *tDCS Stimulation* and *Congruency, F*(1, 69) = .889, *p* = .41, η^2_p = .02, nor between *tDCS Stimulation* and *Alignment*, *F*(1, 69) = .740, *p* = .48, η^2_p = .02. There was also no significant three-way interaction between our factors, *F*(1, 69) = .527, *p* = .59, η^2_p = .01. We found a significant main effect of the between-subjects factor *tDCS Stimulation*, *F*(1, 69) = 4.87, *p* = .010, η^2_p = .12. An independent sample t-test revealed that anodal stimulation at Fp3 significantly reduced overall performance (*M* = .84, *SD* = .12) averaged across all conditions (congruent/incongruent aligned/misaligned) compared to sham (*M* = .90, *SD* = .06), *t*(46) = 2.02, *p* = .048, η^2_p = .08. Overall performance in the anodal Fp3 group was also significantly reduced compared to that in the anodal PO8 group (*M* = .91, *SD* = .03), *t*(46) = 2.64, *p* = .011, η^2_p = .13. No difference was found between the anodal PO8 vs sham group, *t*(46) = .857, *p* = .39, η^2_p = .01.