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Enhancing anger perception with transcranial alternating current stimulation induced gamma oscillations

Agnieszka B Janik[1], Constantin Rezlescu[2,3], Michael J Banissy[1,3]

1. Department of Psychology, Goldsmiths University of London, UK

2. Department of Psychology, Harvard University, USA

3. Institute of Cognitive Neuroscience, University College London, UK

Abstract

Background: In recent years a variety of neuroimaging studies have highlighted a role of neural oscillations in perception and cognition. However, surprisingly little is known about oscillatory activity underlying facial emotion perception. The limited number of studies that have addressed this question indicate that gamma oscillations are one mechanism underlying this process.

Objective: The present study aimed to further elucidate the role of neural oscillations within the gamma range in facial emotion perception in healthy adults by using transcranial alternating current stimulation (tACS).

Methods: To that effect we carried out three experiments with separate groups of participants using tACS to modulate occipital oscillations while participants completed facial anger and facial identity tasks.

Results: The results of these experiments indicated that modulating occipital gamma with 40 Hz tACS enhances facial anger perception.

Conclusion: This finding implicates an important role of occipital gamma oscillations in facial emotion perception.

Introduction

Recently there has been a great interest in documenting the role of neural oscillations and synchrony in perception and cognition (Ward, 2003; Marshall & Binder, 2013). For example, neural activity in the gamma band has been linked to temporal binding and gestalt perception (e.g. Brock et al., 2002; Singer, 2001). Moreover, various frequencies within the gamma range have been found to have different functional roles in low-level visual processing (e.g. in contrast perception; Laczó, Antal, Niebergall, Treue, & Paulus, 2012). Further, disrupted oscillatory activity is often associated with various cognitive and perceptual impairments in a variety of disorders (e.g. Uhlhaas, Haenschel, Nikolić & Singer, 2008; Başar & Güntekin 2008).

Despite this, surprisingly little is known about neural oscillatory activity underlying facial emotion perception. Studies exploring this question have indicated that gamma oscillations are one mechanism underlying this process (Sato et al., 2011; Balconi & Pozzoli, 2007, Tai-Ying Liu et al., 2012). For example, in groups with deficits in emotion perception, such as Autism Spectrum Disorders (ASD; Uljarevic & Hamilton, 2013), gamma oscillations have been reported to be reduced when perceiving emotion from faces (Wright et al., 2012; Gross et al., 2012).

While many of our insights into the role of neural oscillations in perception and cognition are drawn from neuroimaging, recently a number of studies have utilised

transcranial alternating current stimulation (tACS) as a tool to probe the functional role of specific oscillations on performance. tACS is a relatively novel non-invasive brain stimulation technique that can be used to modulate cortical activity in a frequency dependent manner (Antal & Paulus, 2013). For example, in the visual domain tACS stimulation in the beta band evokes phosphenes in illuminated settings while tACS stimulation in the alpha band evokes phosphenes in the dark (Kanai, Chaieb, Antal, Walsh & Paulus, 2008). It is also possible to use tACS to modulate cognitive and perceptual performance. For instance, Polanía, Nitsche, Korman, Batsikadze and Paulus (2012) demonstrated that tACS induced synchronization in the theta range over fronto-parietal region results in enhanced performance on a visual memory task, and Laczó and colleagues (2012) have shown that modulating occipital gamma with tACS can improve contrast perception.

While previous studies have used other forms of transcranial current stimulation (tCS) to study social perception abilities (e.g. Lafontaine et al., 2013; Tseng et al., 2014; Romanska et al., In Press), to date no study has used tACS to examine the role of cortical oscillations in social perception. The advantage of tACS over other types of tCS (e.g. transcranial direct current stimulation or transcranial random noise stimulation) is that it can not only provide information about brain areas involved in social perception, but also about the role individual frequency bands play in this process (Antal &Paulus, 2013). Based on prior findings linking occipital gamma with facial emotion perception, here we conducted two studies using tACS as a tool to examine the extent to which modulating occipital gamma would influence emotion perception abilities of healthy adults. In the light of previous findings it was

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hypothesised that using tACS to modulate occipital gamma would enhance facial emotion recognition.

Experiment 1: The role of occipital gamma and occipital alpha in anger perception

Experiment 1 used a within participants design in order to examine the degree to which modulating occipital gamma or occipital alpha with tACS would influence facial expression perception. Based on prior work linking occipital gamma to emotion perception abilities (e.g. Wright et al., 2012; Gross et al., 2012) we predicted that modulating occipital gamma with tACS would enhance performance relative to occipital alpha stimulation. Since we had no a priori reason to assume that occipital alpha stimulation would differ from sham stimulation, this form of stimulation was chosen as an active control condition in order to examine the extent to which occipital gamma stimulation may influence performance in a frequency specific manner.

Experiment 1: Method

Participants

30 healthy adult participants (21 female, 9 male, mean age 25.33 ± 7.04) took part in this experiment. All participants were healthy volunteers, without any known developmental or neurological disorders and no contraindications to tACS. They were naive with respect to the experimental hypothesis. Participants provided written informed consent to take part in the experiment. They were either paid £5 for participating in the experiment or were awarded course credits.

Task

To examine facial expression abilities, the Cambridge Face Perception Angry Expression (CFPT-Angry) was used. In each trial participants were simultaneously presented with a row of six frontal view pictures of a model showing different degrees of anger at 0, 8, 16, 24, 32 and 40% morphed with a neutral expression (Fig. 1a). The stimuli were constructed from male and female images taken from the Radboud Faces Database (Langner et al., 2010). The participants' task was to sort these images from the least to most angry by moving pictures with a computer mouse to what they believed was their correct position. This task consisted of ten test trials and two practice trials. Participants were allocated 1 minute per trial. Performance on this task was measured using an error score representing total deviations calculated by summing the deviations of each image from its correct location. For instance if the picture was three spaces from its correct position the error score for that trial would be three. Error scores on each trial were summed to determine the total number of errors. We then used this to calculate the percentage of correct responses. Chance performance for CFPT-Angry is 36%.

Stimulation Parameters

A battery-driven DC-Plus stimulator (neuroConn) was used. Stimulation was delivered using 5 cm x 7cm conductive-rubber electrodes enclosed in saline-soaked sponges. The reference electrode was placed over Cz and the stimulating electrode over Oz, according to the international 10-20 system. Two types of stimulation were delivered: gamma (40 Hz) and alpha (10 Hz). The current intensity was set at peak-to-peak amplitude of 1 mA and the experiment was carried out in an illuminated room.

The stimulation waveform was sinusoidal throughout the whole session with no DC offset. Participants completed CFPT-Angry twice, while tACS within the gamma band and alpha band was delivered. The order of stimulation was counterbalanced across participants to control for a potential practice effect

Experiment 1: Results and Discussion

A paired samples t-test was conducted to compare participants' emotion perception performances following gamma or alpha tACS. This revealed that participants performed better on CFPT-Angry when stimulated within the gamma frequency band compared to stimulation within the alpha range [$t (29) = 2.593$, $p = 0.015$ Cohen's $d = 0.346$] (Fig.1b). Therefore modulating occipital gamma with tACS resulted in an improvement in anger perception abilities. These findings compliment prior brain imaging work linking occipital gamma with facial emotion perception (e.g. Wright et al., 2012; Gross et al., 2012) and suggest that occipital gamma plays a key role in facial emotion processing.
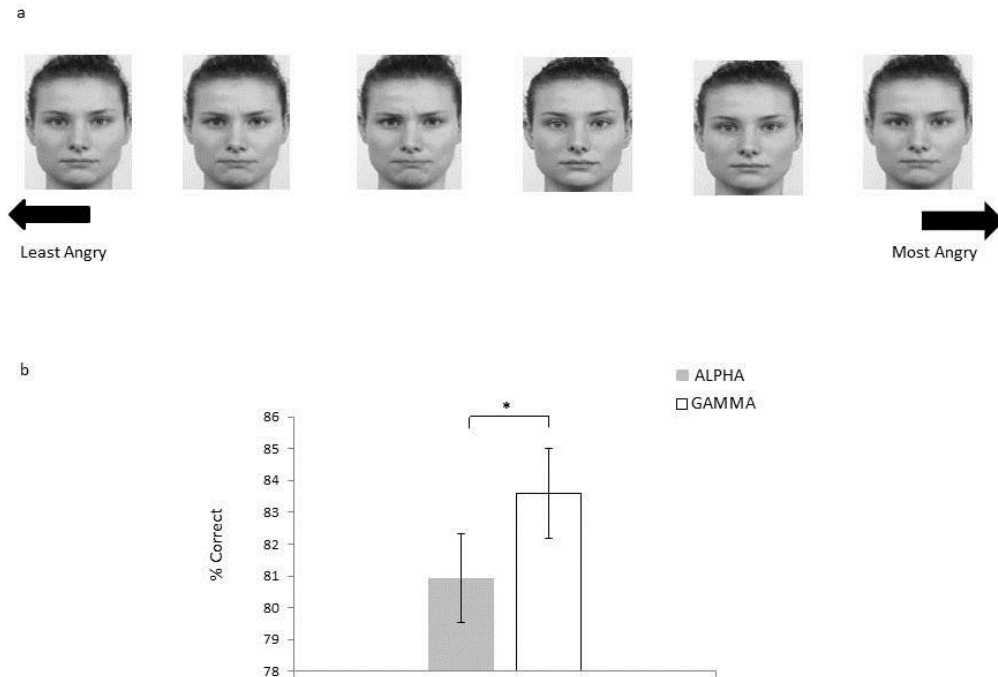
Figure 1. (a) Example of the CFPT-Angry. In this task participants are asked to sort six faces from most angry to least angry. The faces containing varying levels of anger ranging from 0-40%. (b) Modulating occipital gamma with tACS significantly improved participants performance on the CFPT-Angry relative to the tACS in the alpha band. * = P < .05.

Experiment 2: The role of occipital gamma in anger and facial identity perception

Experiment 1 showed that modulating occipital gamma with tACS resulted in an improvement in anger perception relative to tACS in the alpha band. While these findings point to an important role of occipital gamma in anger perception, the extent to which the pattern of data from Experiment 1 holds when comparing performances relative to a condition in which no neurophysiological change due to active tACS took place remains unclear. To address this we ran a second study in a new group of participants in attempt to determine whether modulating occipital gamma with tACS would result in similar improvements in anger perception when compared to sham

tACS. Additionally, we sought to examine the extent to which the improvement seen in Experiment 1 is specific to anger perception by testing participants' abilities to perceive facial identity. Based on our findings from Experiment 1 and prior neuroimaging studies (e.g. Wright et al., 2012; Gross et al., 2012) we predicted that modulating occipital gamma would improve anger perception.

Experiment 2: Method

Participants

22 naive adult participants took part in this experiment (13 female, 9 male, mean age 25.68 ± 5.78). All participants were healthy volunteers, without any known developmental or neurological disorders and no contraindications to tACS. They were naive with respect to the experimental hypothesis. Participants provided written informed consent to take part in the experiment. They were paid £10 for their participation. None of the participants had taken part in Experiment 1.

Tasks

As with Experiment 1, facial emotion perception was measured using the CFPT-Angry (Fig. 1a). To examine facial identity, the Cambridge Face Perception Identity Test (CFPT-Identity; previously referred to as CFPT; Fig. 2) was employed (Duchaine et al., 2007). This task followed a similar setup as the CFPT-Angry, but this time participants were presented with a target male face presented at a three quarters angle and frontal view pictures of six male faces underneath. Participants were asked to sort the six male faces from the most like the target on the left to the least on the right. The six faces were morphed at varying degrees from the target face

and another face at the following levels: containing 88, 76, 64, 52, 40 or 28% of the

target face. As with the CFPT-Angry, participants had 1 minute per each trial. There

were sixteen test trials, eight showing upright faces and eight showing inverted faces,

preceded by two practice trials. Performance was measured using an error score as per

facial emotion version of the task, which was subsequently transformed into a

percentage of correct responses. Each task was performed in a counterbalanced order.
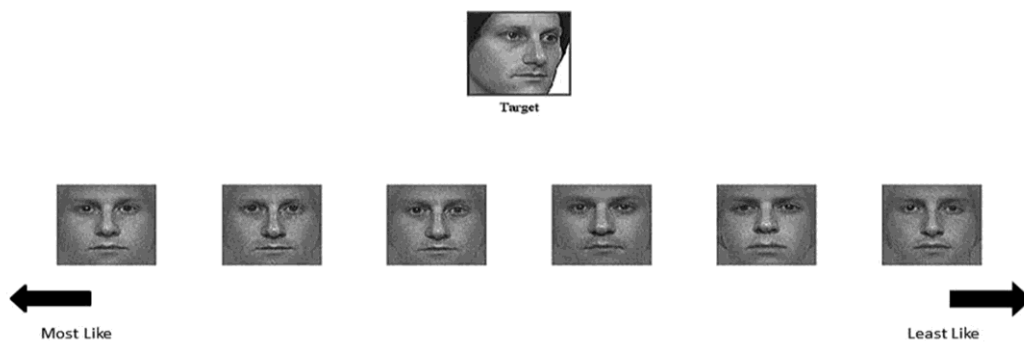

Figure 2. Example of the CFPT-Identity. In this task participants are presented with a
target male face presented at a three quarters angle and frontal view pictures of six
male faces underneath. Participants' task is to sort the six male faces according to the
degree of similarity to the target face. The six faces are morphed at varying degrees
from the target face and another face ranging from 28% to 88% of the target face.
Half of the trials contain upright faces and half inverted faces.

Stimulation parameters

The brain stimulation parameters were identical to Experiment 1. The only difference

was that in this study gamma (40Hz) or sham tACS was applied. In the gamma

condition stimulation began at the start of each task and ceased at the end of each

task. In the sham condition, participants received 10 seconds of stimulation in the

gamma frequency range at the start of the task in order to evoke the somatosensory

sensation of being stimulated. It has been shown that naive subjects cannot distinguish

between sham and active transcranial current stimulation (Gandiga, Hummel and

Cohen, 2006). The stimulation conditions were counterbalanced across participants.

Experiment 2: Results and Discussion

One participant was identified as an outlier on CFPT- Identity inverted trials due to a poor performance close to chance level (2.63 SDs away from the group mean). They were therefore removed from all analyses.

Based on our findings from Experiment 1, planned paired comparisons were conducted comparing performances on the CFPT-Angry. This revealed that participants were more accurate on the CFPT-Angry when stimulated within the gamma band compared to sham stimulation [t (20) = -2.230, p = 0.037, Cohen's d = 0.564] (Fig. 3), thus demonstrating that improvements in anger perception observed in Experiment 1 replicate when modulating occipital gamma relative to a stimulation condition in which no neurophysiological change takes place.

In addition, a 2 (Stimulation Condition) x 3 (Trial Type) ANOVA was conducted to compare participants' performances following tACS across CFPT-Angry, CFPT-Identity upright trials, and CFPT-Identity inverted trials (Fig. 3). This revealed a main effect of task [F(2,40) = 181.009, p < .001, η_p^2 = .901], with participants performing better overall on CFPT-Angry and CFPT-Identity upright trials relative to CFPT-Identity inverted trials (p < .001 Bonferonni Corrected). There was no main effect of stimulation [F (1, 20) = 1.165, p = .293, η_p^2 = .055]. Despite descriptively similar performances on CFPT-Identity upright and CFPT-Identity inverted trials across stimulation conditions (Fig. 3), no significant interaction was found [F (2, 40) = 1.166, p = .322, η_p^2 = .055]. In this regard, while participants showed a significant improvement on CFPT-Angry following occipital gamma stimulation relative to sham (and relative to alpha stimulation in Experiment 1) that was not observed for facial identity perception, the task specific nature of this improvement remains unclear.
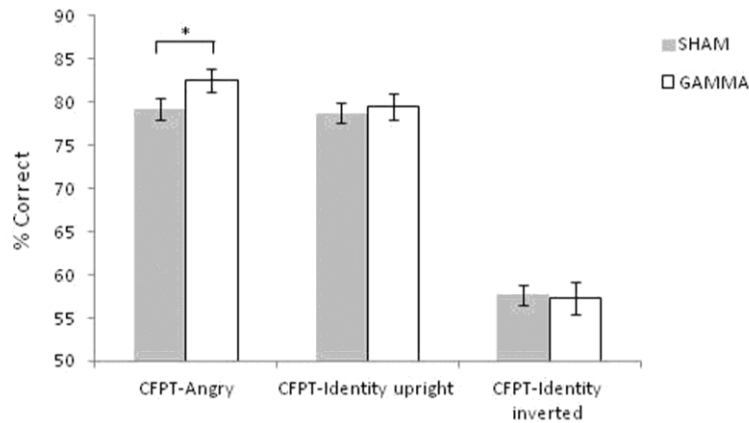
Figure 3. Performances following occipital gamma or sham tACS on the CFPT-Angry, CFPT-Identity upright trials, and CFPT-Identity inverted trials. Occipital gamma significantly enhanced performance on the CFPT-Angry relative to sham stimulation. $* = P < .05$.

Experiment 3: The role of occipital gamma at 40 Hz and 100 Hz in anger perception

The first two studies demonstrated an improvement in facial affect perception measured with CFPT-Anger following tACS at 40 Hz relative to 10Hz stimulation and sham stimulation. While this provides some evidence for frequency-specific modulation of emotion perception following 40Hz stimulation, it could be argued that stimulating at any higher frequency might influence emotion perception. To address

this, a third study was conducted with a new group of participants, where effects of tACS at 40 Hz were compared with stimulation at 100 Hz.

Experiment 3: Method

Participants

15 healthy adult participants (8 female, 7 male, mean age 23.86 ± 3.48) took part in this experiment. None of the participants took part in Experiments 1 or 2. All participants reported to have no known developmental or neurological disorders and no contraindications to tACS. They were naive regarding the experimental hypothesis. Participants provided written informed consent and were paid £20 in return for taking part in this experiment.

Task

To examine facial affect perception, the same Cambridge Face Perception Anger Test (CFPT-Anger) was used, as in Experiment 1 and 2. Performance on this task was measured using percentage of correct responses.

Stimulation Parameters

The equipment and all stimulation parameters were identical to Experiment 1 and 2. The only difference was that in this study gamma at 40Hz or 100 Hz tACS was applied. Stimulation began at the start of CFPT-Anger task and ceased at the end of it with 5second fade-in and fade-out time. Participants performed the task twice, three days apart. The stimulation conditions were counterbalanced across participants.

Experiment 3: Results and Discussion

A paired samples t-test was conducted to compare participants' anger perception following tACS in the gamma frequency band at 40 Hz and 100 Hz. The results indicated that participants' performance on CFPT-Anger was better when stimulated with 40 Hz compared to stimulation with 100 Hz [t (14) = 3.644, p = 0.003 Cohen's d = 0.730] (Fig. 4). Therefore the improved performance on CFPT-Anger appears specific to 40Hz stimulation and is not simply a result of delivering tACS at a higher frequency.
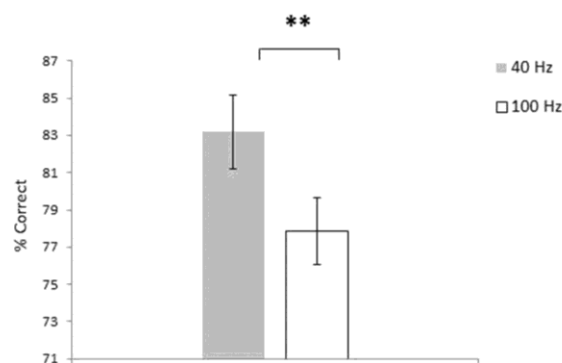

Figure 4. Performances following occipital gamma tACS at 40 Hz and 100 Hz on the CFPT-Angry. Occipital gamma delivered at 40 Hz significantly enhanced performance on the CFPT-Angry relative to stimulation at 100 Hz. * * = P < .005.

General Discussion

The aim of this study was to explore the role of neural oscillatory activity within the gamma frequency range in emotion perception using tACS. Across the three studies, we show that tACS in the gamma band at 40 Hz significantly facilitates facial anger perception abilities relative to tACS in the alpha band (Experiment 1), sham tACS (Experiment 2), and tACS delivered at 100 HZ (Experiment 3). These findings compliment prior neuroimaging work demonstrating the role of occipital gamma in facial emotion processing (e.g. Wright et al., 2012; Gross et al., 2012) by

showing that directly modulating occipital gamma activity at 40 Hz with tACS results in improved facial anger perception.

The findings provide further evidence for the idea that tACS is a powerful brain stimulation technique capable of interacting with the ongoing brain activity and producing tangible outcomes, in this case enhanced processing of emotions. Although the exact mechanisms of tACS are not entirely understood (Antal & Paulus, 2013) our results suggest that tACS is indeed able to target a particular brain area of interest and entrain neural oscillatory activity in the frequency of stimulation. Our findings that we are able to enhance facial anger perception using tACS highlights the potential utility of this technique as a tool for modulating facial emotion processing and add to the growing literature showing that tACS can be used to successfully modulate human perception and cognition (e.g. Laczó et al., 2012; Polanía et al., 2012; Santarnecchi et al., 2013). The findings also raise the interesting possibility about the potential to use tACS to modulate occipital gamma in conditions where reduced levels of occipital gamma have been associated with declines in facial emotion perception (e.g. Gross et al., 2012). It is of note, however, that given the likely variability in terms of levels of cortical excitation between typical and atypical groups (e.g. Coghlan et al., 2012; Krause & Cohen Kadosh, 2014) extensions to atypical groups should be approached with caution.

Additionally, as various frequencies and brain structures have been implicated in emotional processing (e.g. Güntekin & Başar, 2014; Güntekin and Başar, 2009) it is also feasible to suspect that not just occipital gamma, but also other frequencies distributed across a number of different cortical regions are involved in facial emotion recognition. For example, it has been found that greater theta synchronization is associated with explicit recognition of facial expressions of emotions as opposed to

neutral faces, especially in individuals who report to be more emotionally involved (Knyazev, Slobodskoj-Plusnin, & Bocharov, 2009). While we found frequency specific improvements in performance following gamma stimulation at 40 Hz relative to 10Hz and 100 Hz tACS, , it will also be interesting to examine the role of other cortical oscillations in emotion processing with future work.

It is also important to consider that our studies focussed on the perception of anger, thus the extent to which our findings hold for all or some emotions remains unclear. Prior work has suggested that enhanced gamma power in this region also facilitates processing of other types of emotions (e.g. Wright et al., 2012; Gross et al., 2012). Based on our data we can be confident that this result holds for anger perception, but we would flag caution with regards to inferences about other emotional expressions.

Finally, some discussion is warranted in relation to the task specific nature of our effects. We observed significant improvements in anger perception (Experiment 1 and 2), but did not observe any significant modulation of facial identity perception (Experiment 2). While this may hint at task-specificity, a difference between significance and non-significance is not necessarily by itself significantly different (Gelman & Stern, 2006; Nieuwenhuis, Forstmann, & Wagenmakers, 2011). Given that we did not observe a significant interaction between task type (anger perception, facial identity perception of upright faces, facial identity perception of inverted faces) and stimulation in Experiment 2, we are therefore cautious about making inferences about task-specific role of occipital gamma in facial emotion versus facial identity processing. At least two reasons may account for the lack of interaction found in Experiment 2: 1) the interaction in Experiment 2 may suffer from reduced statistical power and / or 2) given that occipital gamma has been linked to holistic processing

(Singer, 2001; Rodriguez et al., 1999) it is feasible that these processes may also be important for facial identity perception, and thus delivering tACS in this frequency may affect both anger and identity perception. To date relatively few studies have examined the role of cortical oscillations in facial identity perception. This is an important avenue to explore in future studies.

Conclusions

In summary, here we show that modulating occipital gamma at 40 Hz enhances the perception of facial emotion across three studies. Our findings highlight that gamma oscillations play a key role in facial anger perception, and show that it is possible to enhance this ability in healthy adults by modulating occipital gamma with tACS.

Disclosure Statement

There were no financial interests or benefits arising from the direct applications of this research.

Author contributions

ABJ and MJB developed the study concept and design. CFPT-Angry was developed by CR and Tirta Susilo. Testing and data collection were performed by ABJ. ABJ performed the data analysis. All authors contributed to the manuscript preparation.

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