Brain Stimulation xxx (2015) 1–6

Contents lists available at ScienceDirect

Brain Stimulation

journal homepage: www.brainstimjrnl.com

Original Research

Enhancing Anger Perception With Transcranial Alternating Current Stimulation Induced Gamma Oscillations

Agnieszka B. Janik [a,*], Constantin Rezlescu [b,c], Michael J. Banissy [a,c]

[a] Department of Psychology, Goldsmiths University of London, UK
[b] Department of Psychology, Harvard University, USA
[c] Institute of Cognitive Neuroscience, University College London, UK

ARTICLE INFO

Article history:
Received 25 February 2015
Received in revised form
19 June 2015
Accepted 19 July 2015
Available online xxx

Keywords:
Transcranial alternating current stimulation
tACS
Emotion perception
Neural oscillations
Gamma

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 [18,30]. For example, neural activity in the gamma band has been linked to temporal binding and gestalt perception (e.g. Refs. [4,25]). 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; [15]). Further, disrupted oscillatory activity is often associated with various cognitive and perceptual impairments in a variety of disorders (e.g. Refs. [3,28]).

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 [2,24,26]. For example, in groups with deficits in emotion perception, such as Autism Spectrum Disorders (ASD; [29]), gamma oscillations have been reported to be reduced when perceiving emotion from faces [9,31].

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 utilized 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 [1]. 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 [12]. It is also possible to use tACS to modulate cognitive and perceptual performance. For instance [20], demonstrated that tACS induced synchronization in the theta range over fronto-parietal region results in enhanced performance on a visual memory task, and [15] have shown that modulating occipital gamma with tACS can improve contrast perception.

ABJ is supported by a PhD Studentship from the Economic and Social Research Council. CR is supported by a Marie Curie international Outgoing Fellowship. This work was supported by an Economic and Social Research Council (ES/K00882X/1) grant awarded to MJB.

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.

* Corresponding author. Department of Psychology, Goldsmiths University of London, Ben Pimlott Building, London SE14 6NW, UK.
E-mail address: a.janik@gold.ac.uk (A.B. Janik).

http://dx.doi.org/10.1016/j.brs.2015.07.032
1935-861X/

While previous studies have used other forms of transcranial current stimulation (tCS) to study social perception abilities (e.g. [16,21,27]), 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 [1]. 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 hypothesized 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. Refs. [9,31]) 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 [17]. 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 min 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 × 7 cm 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

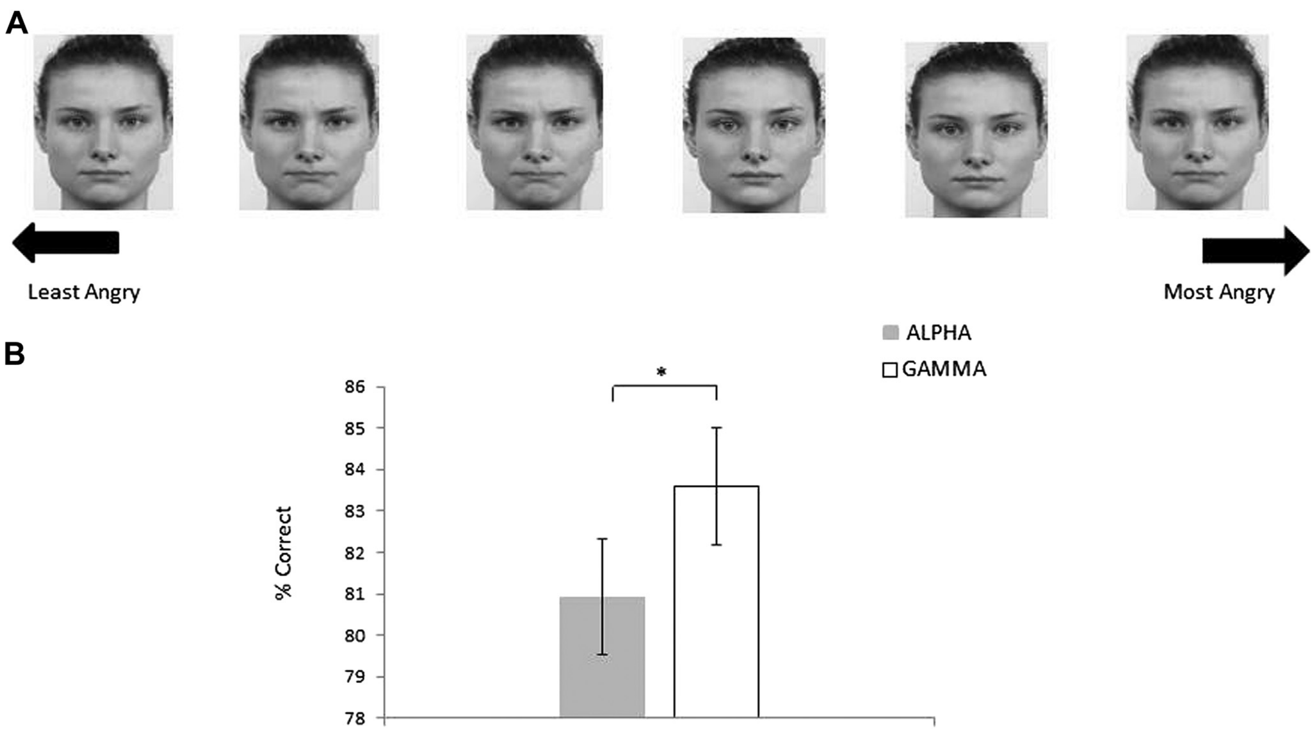

Figure 1. (A) Example of the CFPT-Angry. In this task participants are asked to sort six faces from most angry to least angry. The faces containing varying levels of anger ranging from 0 to 40%. (B) Modulating occipital gamma with tACS significantly improved participants performance on the CFPT-Angry relative to the tACS in the alpha band. * = $P < .05$.

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 [$t(29) = 2.593$, $P = .015$ Cohen's $d = .346$] (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. Refs. [9,31]) and suggest that occipital gamma plays a key role in facial emotion processing.

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. Refs. [9,31]) 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 [6]. 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 min 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.

Stimulation parameters

The brain stimulation parameters were identical to Experiment 1. The only difference was that in this study gamma (40 Hz) 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 s 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 [7]. 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.

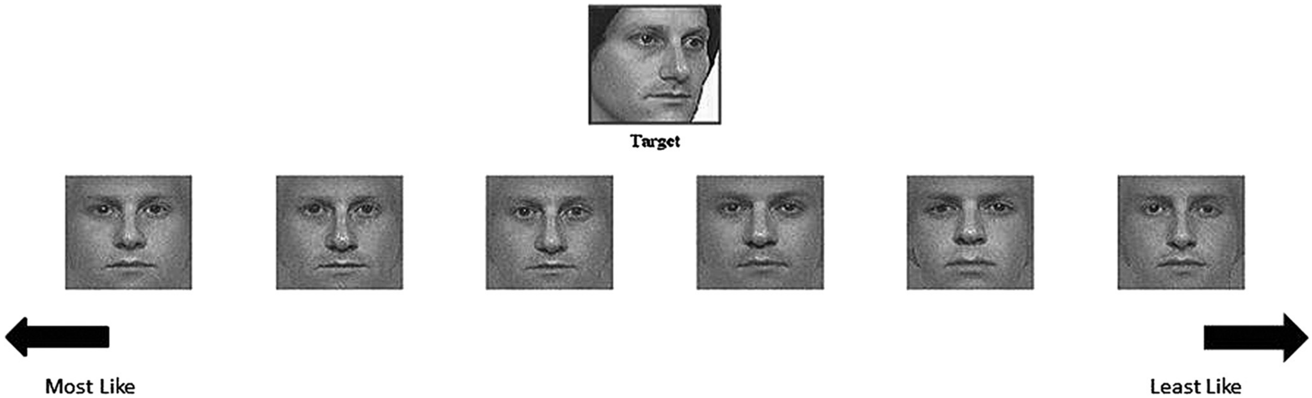

Figure 2. Example of the CFPT-Identity. In this task participants are presented with a target male face presented at a three quarters angle and frontal view pictures of six male faces underneath. Participants' task is to sort the six male faces according to the degree of similarity to the target face. 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.

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 [$t(20) = -2.230$, $P = .037$, Cohen's $d = .564$] (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) × 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 [$F(2,40) = 181.009$, $P < .001$, $\eta_p^2 = .901$], 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 [$F(1,20) = 1.165$, $P = .293$, $\eta_p^2 = .055$]. Despite descriptively similar performances on CFPT-Identity upright and CFPT-Identity inverted trials across stimulation conditions (Fig. 3), no significant interaction was found [$F(2,40) = 1.166$, $P = .322$, $\eta_p^2 = .055$]. 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.

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 10 Hz stimulation and sham stimulation. While this provides some evidence for frequency-specific modulation of emotion perception following 40 Hz 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 40 Hz or 100 Hz tACS was applied. Stimulation began at the start of CFPT-Anger task and ceased at the end of it with 5 s 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 [$t(14) = 3.644$, $P = .003$ Cohen's $d = .730$] (Fig. 4). Therefore the improved performance on CFPT-Anger appears specific to 40 Hz stimulation and is not simply a result of delivering tACS at a higher frequency.

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

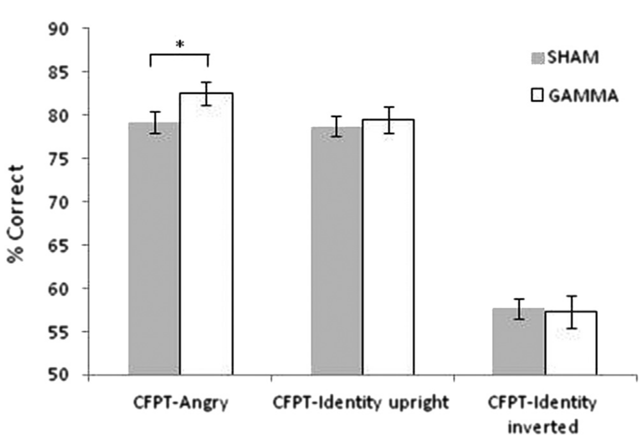

Figure 3. Performances following occipital gamma or sham tACS on the CFPT-Angry, CFPT-Identity upright trials, and CFPT-Identity inverted trials. Occipital gamma significantly enhanced performance on the CFPT-Angry relative to sham stimulation. * = $P < .05$.

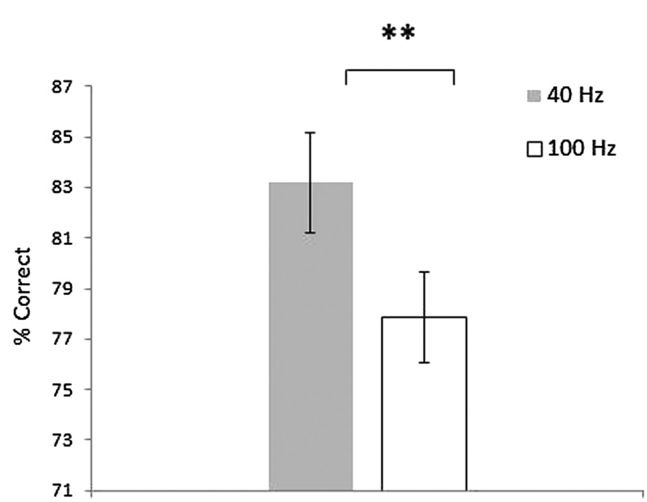

Figure 4. Performances following occipital gamma tACS at 40 Hz and 100 Hz on the CFPT-Angry. Occipital gamma delivered at 40 Hz significantly enhanced performance on the CFPT-Angry relative to stimulation at 100 Hz. ** = $P < .005$.

processing (e.g. Refs. [9,31]) 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 [1] 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. Refs. [15,20,23]). 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. Ref. [9]). It is of note, however, that given the likely variability in terms of levels of cortical excitation between typical and atypical groups (e.g. Refs. [5,14]) extensions to atypical groups should be approached with caution.

Additionally, as various frequencies and brain structures have been implicated in emotional processing (e.g. Refs. [10,11]) 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 [13]. While we found frequency specific improvements in performance following gamma stimulation at 40 Hz relative to 10 Hz 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. Refs. [9,31]). 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 [8,19]. 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 [22,25] 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.

Acknowledgment

We would like to thank Tirta Susilo and Amy Bray for their assistance with this research project.

References

[1] Antal A, Paulus W. Transcranial alternating current stimulation (tACS). Front Hum Neurosci 2013;7:317. http://dx.doi.org/10.3389/fnhum.2013.00317.
[2] Balconi M, Pozzoli U. Event-related oscillations (EROs) and event-related potentials (ERPs) comparison in facial expression recognition. J Neuropsychol 2007;1:283–94.
[3] Başar E, Güntekin B. A review of brain oscillations in cognitive disorders and the role of neurotransmitters. Brain Res 2008;1235:172–93.
[4] Brock J, Brown CC, Boucher J, Rippon G. The temporal binding deficit hypothesis of autism. Dev Psychopathol 2002;14:209–24.
[5] Coghlan S, Horder J, Inkster B, Mendez MA, Murphy DG, Nutt DJ. GABA system dysfunction in autism and related disorders: from synapse to symptoms. Neurosci Behav Rev 2012;36:2044–55.
[6] Duchaine B, Yovel G, Nakayama K. No global processing deficit in the Navon task in 14 developmental prosopagnosics. Soc Cogn Affect Neurosci 2007;2:104–13. http://dx.doi.org/10.1093/scan/nsm003.
[7] Gandiga PC, Hummel FC, Cohen LG. Transcranial DC stimulation (tDCS): a tool for double-blind sham-controlled clinical studies in brain stimulation. Clin Neurophysiol 2006;117:845–50.
[8] Gelman A, Stern H. The difference between "significant" and "not significant" is not itself statistically significant. Am Stat 2006;60:328–31.
[9] Gross E, El-Baz AS, Sokhadze GE, Sears L, Casanova MF, Sokhadze EM. Induced EEG gamma oscillation alignment improves differentiation between autism and ADHD group responses in a facial categorization task. J Neurother 2012;16:78–91.
[10] Güntekin B, Başar E. A review of brain oscillations in perception of faces and emotional pictures. Neuropsychologia 2014;58:33–51.
[11] Güntekin B, Başar E. Facial affect manifested by multiple oscillations. Int J Psychophysiol 2009;71:31–6.
[12] Kanai R, Chaieb L, Antal A, Walsh V, Paulus W. Frequency-dependent electrical stimulation of the visual cortex. Curr Biol 2008;23:1839–43.
[13] Knyazev GG, Slobodskoj-Plusnin JY, Bocharov AV. Event-related delta and theta synchronization during explicit and implicit emotion processing. Neuroscience 2009;164:1588–600.
[14] Krause B, Cohen Kadosh R. Not all brains are created equal: the relevance of individual differences in responsiveness to transcranial electrical stimulation. Front Syst Neurosci 2014;8. http://dx.doi.org/10.3389/fnsys.2014.00025.
[15] Laczó B, Antal A, Niebergall R, Treue S, Paulus W. Transcranial alternating stimulation in a high gamma frequency range applied over V1 improves contrast perception but does not modulate spatial attention. Brain Stimul 2012;5:484–91.
[16] Lafontaine MP, Theoret H, Gosselin F, Lippe S. Transcranial direct current stimulation of the dorsolateral prefrontal cortex modulates repetition suppression to unfamiliar faces: an ERP Study. PLoS One 2013;8(12):e81721. http://dx.doi.org/10.1371/journal.pone.0081721.
[17] Langner O, Dotsch R, Bijlstra G, Wigboldus DHJ, Hawk ST, van Knippenberg A. Presentation and validation of the Radboud Faces Database. Cogn Emot 2010;24:1377–88.
[18] Marshall L, Binder S. Contribution of transcranial oscillatory stimulation to research on neural networks: an emphasis on hippocampo-neocortical rhythms. Front Hum Neurosci 2013. http://dx.doi.org/10.3389/fnhum.2013.00614.
[19] Nieuwenhuis S, Forstmann BU, Wagenmakers EJ. Erroneous analyses of interactions in neuroscience: a problem of significance. Nat Neurosci 2011; 14:1105–7.
[20] Polanía R, Nitsche MA, Korman C, Batsikadze G, Paulus W. The importance of timing in segregated theta phase-coupling for cognitive performance. Curr Biol 2012;22:1314–8.
[21] Romanska A, Rezlescu C, Susilo T, Duchaine B, Banissy MJ. High frequency transcranial random noise stimulation enhances perception of facial identity. Cereb Cortex 2015. http://dx.doi.org/10.1093/cercor/bhv016.

[22] Rodriguez E, George N, Lachaux JP, Martinerie J, Renault B, Varela FJ. Perception's shadow: long-distance synchronization of human brain activity. Nature 1999;397:430–3.
[23] Santarnecchi E, Polizzotto NR, Godone M, et al. Frequency-dependent enhancement of fluid intelligence induced by transcranial oscillatory potentials. Curr Biol 2013;23:1449–53.
[24] Sato W, Kochiyamab T, Uonoc S, et al. Rapid amygdala gamma oscillations in response to fearful facial expressions. Neuropsychologia 2011;49:612–7.
[25] Singer W. Consciousness and the binding problem. Ann N Y Acad Sci 2001;929:123–46.
[26] Liu Tai-Ying, Hsieh Jen-Chuen, Chen Yong-Sheng, Tu Pei-Chi, Su Tung-Ping, Chen Li-Fen. Different patterns of abnormal gamma oscillatory activity in unipolar and bipolar disorder patients during an implicit emotion task. Neuropsychologia 2012;5:1514–20.
[27] Tseng L-Y, Tseng P, Liang W-K, et al. The role of superior temporal sulcus in the control of irrelevant emotional face processing: a transcranial direct current stimulation study. Neuropsychologia 2014;64:124–33.
[28] Uhlhaas PJ, Haenschel C, Nikolić D, Singer W. The role of oscillations and synchrony in cortical networks and their putative relevance for the pathophysiology of schizophrenia. Schizophr Bull 2008;34:927–43.
[29] Uljarevic M, Hamilton A. Recognition of emotions in autism: a formal meta-analysis. J Autism Dev Disord 2013;43:1517–26.
[30] Ward LM. Synchronous neural oscillations and cognitive processes. Trends Cogn Sci 2003;7:553–9.
[31] Wright B, Alderson-Day B, Prendergast G, et al. Gamma activation in young people with autism spectrum disorders and typically-developing controls when viewing emotions on faces. PLoS One 2012;7(7):e41326. http://dx.doi.org/10.1371/journal.pone.0041326.