cortex 67 (2015) 74–82

Available online at www.sciencedirect.com

ScienceDirect

Journal homepage: www.elsevier.com/locate/cortex

Research report

Functional role of frontal alpha oscillations in creativity

Caroline Lustenberger [a], Michael R. Boyle [a,b], A. Alban Foulser [c], Juliann M. Mellin [a] and Flavio Fröhlich [a,b,d,e,f,*]

[a] Department of Psychiatry, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
[b] Department of Biomedical Engineering, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
[c] Department of Psychology, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
[d] Department of Cell Biology and Physiology, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
[e] Neurobiology Curriculum, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
[f] Neuroscience Center, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

ARTICLE INFO

Article history:
Received 3 October 2014
Reviewed 1 November 2014
Revised 29 January 2015
Accepted 19 March 2015
Action editor Sven Bestmann
Published online 1 April 2015

Keywords:
Transcranial alternating current stimulation (tACS)
Torrance Test of Creative Thinking (TTCT)
Divergent thinking
Alpha power
Gamma activity

ABSTRACT

Creativity, the ability to produce innovative ideas, is a key higher-order cognitive function that is poorly understood. At the level of macroscopic cortical network dynamics, recent electroencephalography (EEG) data suggests that cortical oscillations in the alpha frequency band (8–12 Hz) are correlated with creative thinking. However, whether alpha oscillations play a functional role in creativity has remained unknown. Here we show that creativity is increased by enhancing alpha power using 10 Hz transcranial alternating current stimulation (10 Hz-tACS) of the frontal cortex. In a study of 20 healthy participants with a randomized, balanced cross-over design, we found a significant improvement of 7.4% in the Creativity Index measured by the Torrance Test of Creative Thinking (TTCT), a comprehensive and most frequently used assay of creative potential and strengths. In a second similar study with 20 subjects, 40 Hz-tACS was used instead of 10 Hz-tACS to rule out a general "electrical stimulation" effect. No significant change in the Creativity Index was found for such frontal 40 Hz stimulation. Our results suggest that alpha activity in frontal brain areas is selectively involved in creativity; this enhancement represents the first demonstration of specific neuronal dynamics that drive creativity and can be modulated by non-invasive brain stimulation. Our findings agree with the model that alpha recruitment increases with internal processing demands and is involved in inhibitory top-down control, which is an important requirement for creative ideation.

Abbreviations: TTCT, Torrance Test of Creative Thinking; tACS, transcranial alternating current stimulation.

* *Corresponding author.* 115 Mason Farm Rd. NRB 4109F, Chapel Hill, NC 27599, USA.
E-mail address: flavio_frohlich@med.unc.edu (F. Fröhlich).

http://dx.doi.org/10.1016/j.cortex.2015.03.012
0010-9452/

1. Introduction

Creativity, the ability to produce novel and useful work, is one of the most extraordinary capabilities of the human mind (Sawyer, 2011). Yet, the neural basis of creativity remains poorly understood (Dietrich & Kanso, 2010). At the level of macroscopic brain dynamics measured with electroencephalography (EEG), oscillatory activity in the alpha frequency band (8–12 Hz) correlates with creative ideation (Fink & Benedek, 2014). In particular, creative idea generation was associated with increased oscillation power in the alpha band in prefrontal and parietal cortical areas (Fink, Benedek, Grabner, Staudt, & Neubauer, 2007; Jauk, Benedek, & Neubauer, 2012). Also, enhanced alpha power was more pronounced in highly creative people, for more original ideas, and during demanding creative tasks (Fink & Benedek, 2014). In further support of the importance of alpha oscillations, creativity-enhancing, behavioral interventions were associated with increased alpha recruitment, especially at frontal brain sites (Fink, Grabner, Benedek, & Neubauer, 2006; Fink, Schwab, & Papousek, 2011). Despite this convergence of evidence of an association between alpha oscillations and creativity, it has remained unknown whether alpha activity is causally involved in creative ideation since previous studies of cognitive enhancement by brain stimulation have focused on targeting specific brain areas and not network dynamics (Luft, Pereda, Banissy, & Bhattacharya, 2014). Transcranial alternating current stimulation (tACS) is a non-invasive brain stimulation modality that applies weak, oscillating electric currents to the scalp to enhance endogenous cortical oscillations at the applied frequency (Herrmann, Rach, Neuling, & Struber, 2013; Schmidt, Iyengar, Foulser, Boyle, & Frohlich, 2014; Vossen, Gross, & Thut, 2014). TACS has recently provided causal evidence for oscillations in specific frequency bands mediating memory consolidation, motor control, sensory processing, and fluid intelligence (Fröhlich, 2014; Herrmann et al., 2013; Santarnecchi et al., 2013). Alpha oscillations are likely generated and modulated by thalamo-cortical and intra-cortical circuits (Bollimunta, Mo, Schroeder, & Ding, 2011; Hindriks & van Putten, 2013) and are therefore susceptible to cortical brain stimulation. Indeed, recent advances in simultaneous EEG and tACS have demonstrated that stimulation in the alpha frequency band selectively enhanced alpha oscillations during and briefly after stimulation (Helfrich, Schneider, et al., 2014; Zaehle, Rach, & Herrmann, 2010). We here used bifrontal tACS in the alpha frequency range (10 Hz-tACS) to determine if alpha oscillations play a functional role in creativity. In a second experiment we applied 40 Hz-tACS to rule out a general "electrical stimulation" effect.

2. Materials and methods

The study is separated into two experiments of which both employed identical methods with the exception of the tACS frequencies used. In Experiment 1, 10 Hz-tACS was applied and in Experiment 2, 40 Hz-tACS was used.

2.1. *Participants*

All participants were recruited from the University of North Carolina at Chapel Hill (UNC) community and signed written consent prior to participation. This study was approved by the UNC IRB. Exclusion criteria were a history of neurologic or psychiatric illness, family history of psychopathology, chronic diseases, current use of psychoactive agents or other medications, brain implants/devices, history of brain surgery, and pregnancy.

Experiment 1:

Twenty healthy, right-handed participants (5 males, 15 females) aged 19–30 years (20.9 ± 2.7 years; Mean ± SD) were included in the study.

Experiment 2:

Twenty healthy, right-handed participants (13 males, 7 females) aged 18–30 years (20.5 ± 3.2 years; Mean ± SD) were included in the study.

2.2. *Study procedure*

A randomized, crossover design was applied in both experiments; participants were blinded to the stimulation condition and independent scoring of the creativity assay was done by a third party unaware of the study design. Participants attended two experimental sessions on the same day consisting of the two parallel forms of the creativity tests [Torrance Test of Creative Thinking (TTCT)] during which participants received either active sham or tACS. The two tests were separated by a 30 min break to minimize contamination of the second session with outlasting effects of the stimulation during the first session (Fig. 1). During one of the two sessions (verum condition), 10 Hz-tACS (Experiment 1) or 40 Hz-tACS (Experiment 2) was administered for the entire duration of the TTCT (30 min). In the other session, 10 Hz-tACS or 40 Hz-tACS, respectively, was administered for 5 min (active sham condition). We chose the duration of 5 min for the active sham stimulation to improve the blinding to the condition since tACS of different frequencies and amplitudes generates neurosensory effects (Kanai, Chaieb, Antal, Walsh, & Paulus, 2008; Raco, Bauer, Olenik, Brkic, & Gharabaghi, 2014; Turi et al., 2013). After completing the first test, participants were asked to wait patiently for 30 min. Magazines were provided for the participant to read while they waited in between tests. After 30 min, participants were given the other form of the TTCT and received either verum or sham stimulation. All iterations of form type, stimulation type, and session order were randomized and balanced; each participant received both verum and sham stimulation. After the second testing, participants were asked whether or not they believe they received stimulation.

2.3. *TTCT – figural task*

The TTCT is the most widely used and well-known measure of creativity (Baer, 1993; Kim, 2006). It was developed to measure divergent thinking, which is a central aspect of creativity. We used the figural version of the task that comes with the two parallel forms A and B (Torrance, 1998). Both