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Modulation of the frontal-parietal network by low intensity anti-phase 20 Hz transcranial electrical stimulation boosts performance in the attentional blink task

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A B S T R A C T

Performance in the attentional blink task has been demonstrated to be directly influenced by alpha and beta neural oscillatory activity. In two experiments we stimulated the right parietal cortex and left frontal cortex with transcranial alternating current stimulation. For the first experiment we targeted only the right parietal cortex and found a non-significant increase in performance from 20 Hz stimulation. In the second experiment we applied two stimulators to the right parietal and left frontal cortex and found a significant increase in performance from 20 Hz tACS with a phase difference of 180°. Since low intensity stimulation has been shown to inhibit cortical excitability, and anti-phasic stimulation has been hypothesized to decrease presynaptic activation in one region and drive postsynaptic spikes in the other, we suggest that low intensity anti-phasic 20 Hz stimulation inhibited the parietal cortex, thereby disinhibiting the frontal cortex. This visual attention mechanism supposedly reduces processing of distractor stimuli and enhances processing of target stimuli. This study reveals that the frontal-parietal visual attention network may be modulated with low intensity 20 Hz anti-phase tACS.

1. Introduction

For the past few decades a phenomenon termed the attentional blink (AB) has been used to investigate conscious perception of incoming stimuli (Kim and Blake, 2005). The AB occurs when participants fail to detect a second target stimuli (T2) presented between 200 and 500 ms after an initial target in a rapid serial visual presentation (RSVP) scheme (Raymond et al., 1992). To investigate the neural process of this lapse in conscious perception, many have investigated the neural structure of the AB. Using fMRI, a large network of brain regions comprised of the occipital cortex, right posterior parietal cortex, and the left frontal cortex have been reported (Martens and Wyble, 2010; Williams et al., 2008; Palva and Palva, 2007; Gross et al., 2004). Furthermore, lesions to the right inferior parietal cortex and lateral frontal cortex have shown to prolong the AB (Husain and Rorden, 2003; Husain et al., 1997).

To investigate the neural oscillations of the AB, electroencephalography (EEG) has been used to investigate inter-area phase locking for successful compared to unsuccessful detection of T2 stimuli (see Janson and Kranczioch, 2011 for review). Studies have reported that conscious perception of T2 occurs from long-range phase synchronization within the low beta range (~15) between the right posterior parietal and left frontal cortical regions, corresponding to a visual-attention network (Kranczioch et al., 2007; Gross et al., 2004). Moreover, other studies have shown that successful compared with unsuccessful detection of T2 is associated with both an increase in beta band coherence and a decrease in alpha band coherence between frontal and parietal regions (Kranczioch et al., 2007). It is suggested that successful conscious perception of a stimulus requires the dynamic interaction between beta oscillations that facilitate perception, and a pre-stimulus inhibitory mechanism indexed by the decrease in alpha oscillations prior to T2 (Janson et al., 2014; Klimesch et al., 2007; Kranczioch et al., 2007; Hanslmayr et al., 2005; Van Dijk et al., 2008). Further evidence derives from studies investigating visual perception using masked stimuli comparing "perceivers", i.e. participants who are able to discriminate between four shortly presented masked stimuli, with "non-perceivers", i.e. individuals whom cannot (Hanslmayr et al., 2007). Unlike perceivers whom display alpha oscillations prior to stimulus onset and during resting state, alpha oscillations in non-perceivers are absent. Together these studies add support to the notion that conscious perception of rapid stimuli occurs from at least two neural processes reflected by alpha and beta oscillations (Janson et al., 2014; Janson and Kranczioch, 2011; Kranczioch et al., 2007).

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For this study we tested the influence of alpha and beta oscillations directly by using a relatively novel and non-invasive stimulation technique, transcranial alternating current stimulation (tACS) which modulates large-scale cortical networks by entraining neural oscillations within the brain (Ali et al., 2013; Thut et al., 2011). For experiment 1, we aimed to test whether inducing alpha and beta oscillations with 10 Hz and 20 Hz stimulation, respectively would have reverse effects on performance of the attentional blink paradigm. This hypothesis was based on the notion that successful compared with unsuccessful detection of T2 is associated with both an increase in beta band coherence and a decrease in alpha band coherence between frontal and parietal regions (Kranczioch et al., 2007). For experiment 2, we hypothesized that conscious perception should increase from in-phase (0°/synchronized) 20 Hz stimulation. This was based on a previous study showing that synchronized beta oscillations in the frontal-parietal network correspond with successful T2 target detection (Gross et al., 2004). For the first experiment we applied sham, 10 Hz, and 20 Hz tACS on the right parietal cortex to test whether conscious perception of T2 stimuli can be modulated. In the second experiment we applied an additional stimulator on the left frontal area with a phase angle difference of 180° and 0° for both 10 Hz and 20 Hz tACS. This latter experiment allowed us to test whether modulation of synchronizing alpha or beta oscillations between the frontal and parietal areas influences conscious perception of T2.

2. Materials and methods

2.1. Participants

In total, thirty-five participants naïve to the purpose of the experiment ranging between 18 and 29 years old and with normal or corrected to normal visual acuity were screened for psychoactive medication, prior seizures and/or neurological disorders. Participants read and signed a written informed consent which was approved by The HSE Committee on Interuniversity Surveys and Ethical Assessment of Empirical Research in accordance with the Declaration of Helsinki. For experiment one, two participants were removed from the analysis: one participant was omitted from the analysis due to reporting visual phosphenes, another as the result of high accuracy (scoring 92% for detection of T2; i.e. a non-perceiver). In total, eighteen participants (10 females; mean age 20.66; SD = 2.53) were included in the analysis. For Experiment 2, fifteen additional healthy volunteers (13 females; mean age 20.26; SD = 2.35) participated in the study.

2.2. Stimuli and Procedure

Both experiments were conducted in a specialized room: isolated from sound and light. The distance between participants and the screen was set at a distance of 60 cm. Stimulation was generated by a computer with Windows XP professional operation system on a 19-inch ViewSonic P98F+ color display monitor. Responses were reported manually by pressing keys on a keyboard. We used rapid serial visual presentation (RSVP) task from a standardized paradigm (Shapiro et al., 1994) downloaded from E-prime scripts (step.psy.cmu.edu/scripts/Attention/Shapiro1994.html). Each trial consisted of 24 sequential frames of centred letters each displaying for 15 ms at a visual angle of 0.82°. Each letter followed an inter-stimulus interval of 75 ms, yielding a stimulus-onset asynchrony (SOA) at 90 ms. Presentation rate was presented 11.11 letters per second. Using a grey background, T1 was displayed in white on the 15th frame while all other distractors and T2 were displayed in black. T2 was presented at various time lags: 1, 3, 4, and 6 frames after T1 (SOA: 90 ms, 270 ms, 360 ms, 540 ms, respectively). T1 was presented as either letter A, T or H, while T2 was presented as the letter X, which did not appear as a distractor. Each block consisted of 120 trials, 60 of which did not contain T2, and 15 trials each displaying T2 at a lag of 1, 3, 4, and 6.

2.3. tACS Procedure

For both experiments, all stimulation protocols were administered within a single session, applied online. For experiment one, participants received nine blocks receiving three stimulation protocols (sham, 10 Hz and 20 Hz) repeated three times in a single session. For the second experiment, fifteen blocks were given for each stimulation protocol (sham, 10 Hz at 0°, 10 Hz at 180°, 20 Hz at 0° and 20 Hz at 180°), repeating each stimulation three times. Stimulation procedures were double-blind, randomized in a Latin-Square design to reduce learning effects across stimulation protocols. Breaks of 5 min were provided between each stimulation protocol. At the end of the experiment participants were asked whether they had experienced any unusual sensations. All except one participant reported no visual phosphenes. Sham stimulation was applied using low-frequency transcranial random noise stimulation (tRNS) between 0.1–100 Hz for 30 s with a 10-second fade-in/fade-out. This choice of sham stimulation is explained in a previous tACS experiment (Yaple et al., 2017). For 10 Hz and 20 Hz tACS, the waveform of the stimulation was sinusoidal, and there was no direct current offset. Since 10 Hz and 20 Hz on occipital areas has been shown to induce appearance of phosphenes at an intensity as low as 750 μA (Kanai et al., 2010; Raco et al., 2014), and aftereffects are shown to reduce at intensities at 400 μA (Paulus, 2010), the current intensity was set at a low intensity (350 μA). Impedance levels for both experiments were kept below 10 kΩ. For experiment 1, stimulation was delivered during task performance using a battery-operated stimulator system (BrainStim, EMS Medical, Bologna, Italy) using a saline-soaked 7 × 5 electrode. Stimulation protocols for experiment 1 included sham, 10 Hz, and 20 Hz delivered to the P4 electrode, corresponding with the right posterior parietal cortex (see Fig. 1a). In experiment 2, we applied two stimulators online with a different stimulator system (StarStim 8, Neuroelectrics, Boston, Massachusetts) with circular shaped electrodes (25 cm^2). One stimulator was placed on the P4 electrode position and another was placed on the F3 electrode position These electrodes stimulated with a phase difference of 0° (synchronized) and 180° (desynchronized) for 10 Hz and 20 Hz separately (see Fig. 1b). For both experiments, we chose the right deltoid as the reference electrode, equivalent to cephalic placement (Im et al., 2012). Total duration of the experiment for experiment 1 lasted for no > 35 min; for experiment 2, total duration of the experiment lasted for 50 min.

3. Results

Only trials in which T1 was successfully attended were included in the analysis. Data were analysed using SPSS version 20.0 (SPSS Inc., Natick, USA). For both experiments we performed repeated measures ANOVA tests on the mean detection of T2. For experiment 1, the following independent variables were tested: stimulation protocol (10 Hz, 20 Hz, and sham) and lag condition (1, 3, 4, 6). For the second experiment, we tested the independent variables: stimulation protocol (sham, 10 Hz at 0°, 10 Hz at 180°, 20 Hz at 0° and 20 Hz at 180°) and lag condition (1, 3, 4, 6). Follow-up planned comparisons were corrected using the Fisher's LSD method.

3.1. Experiment 1

Results from the repeated measures ANOVA test revealed a significant main effect of lag ($F_{3,51} = 4.615$; $p = 0.006$; partial $\eta^2 = 0.214$). The main effect of lag demonstrated an attentional blink effect; performance was lower for lag 3 compared to lag 1 ($p = 0.019$), lag 4 ($p = 0.010$), and lag 6 ($p = 0.001$). Fig. 2 displays means and standard errors of lag by frequency (Fig. 2a) and the main effect of frequency (Fig. 2b). The main effect of frequency was near significant ($F_{2,34} = 2.552$; $p = 0.093$; partial $\eta^2 = 0.131$). The interaction effect of lag x frequency was non-significant ($F_{6,102} = 0.738$; $p = 0.620$). Fig. 2c