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Transcranial alternating stimulation in a high gamma frequency range applied over V1 improves contrast perception but does not modulate spatial attention

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Spatial visual attention enhances information processing within its focus. Vision at an attended location is faster, more accurate, of higher spatial resolution, and has an enhanced sensitivity for fine changes. Earlier hypotheses suggest that the neuronal mechanisms of these processes are based on the interactions among different neuronal groups by means of cortical oscillations in the gamma range. The aim of the current study was to modulate these oscillations externally, using a new technique called transcranial alternating current stimulation (tACS). We investigated the effect of covert spatial attention within and outside its focus by probing contrast sensitivity and contrast discrimination at high resolution across the visual field of 20 healthy human subjects. While applying 40, 60, and 80 Hz tAC stimulation over the primary visual cortex (V1), subjects' contrast-discrimination thresholds were obtained using two different conditions: in the first condition we presented a black disc as a peripheral cue that automatically attracted the subject's attention, whereas there was no cue in the second condition. We found that the spatial profile of contrast sensitivity was not affected by the stimulation. Contrast-discrimination thresholds on the other hand decreased significantly during 60 Hz tACS, whereas there was no effect of 40 and 80 Hz stimulation. These results suggest that attention plays an important role in contrast discrimination based on V1 activities that are influences by gamma range tACS stimulation.

Keywords tACS; visual cortex; contrast perception; human; spatial attention

Electrophysiologic and biophysical studies have revealed that synchronized oscillatory activities are common in the primate cortex during different perceptual conditions, and even single neurons are able to resonate and oscillate at multiple frequencies.[1] These oscillations are organized in various complex patterns and different frequency bands

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have been linked to distinct functions. Slower theta (4-8 Hz) and alpha (8-12 Hz) oscillations are believed to be associated with interregional, top-down processing, and cognitive functions such as working memory, semantic memory, or risk identification.[2-5] The beta rhythm (12-20 Hz) is usually desynchronized during motor tasks and synchronized (beta rhythm rebound) shortly after movement[6] and reflects the activity of the motor cortices.[7-10] High-frequency gamma-oscillations (30-80 Hz) have been linked to different perceptual and cognitive functions such as feature binding,[11] formation of percepts, long-term memory,[12,13] learning, and selective attention.[14,15]

Amplitude changes of the oscillations are considered to result from the phase synchronization within local neuronal ensembles and have been linked to cognitive functions such as perception and motor control. The synchronization of oscillatory activity, however, is not constrained to local networks, but can also serve as a tool for the interaction between distant brain areas with diverse functional roles. Single and multiunit electrophysiologic recordings from cat visual cortex have revealed that external stimuli could induce strongly synchronized cortical activity within the 20-80 Hz frequency range inside and between different visual areas.[16-18] It has been hypothesized that the temporal synchronization of the neuronal firing patterns in the visual system can be temporarily organized into functional units, which encode information about single features as well as the whole stimulus to achieve their "binding." After introducing binding in the context of feature integration,[19] the concept has been applied to other domains such as object recognition,[20] memory recall,[21] language processing,[22] and attention.[23]

Attention has been shown to enhance gamma-band activity,[24] to increase gamma-frequency synchronization of neuronal oscillations in monkey visual cortex[14] and to enhance gamma-band coherence among V4 neurons.[25] Attentional influences are not restricted to extrastriate visual areas, since electrophysiologic and imaging studies have documented attentional modulation of visual information processing in V1 as well.[26-28]

Voluntary spatial visual attention serves as a mechanism enabling us to selectively and covertly (i.e., without gaze shifts) direct our limited processing capacity to certain locations of the visual field. Several studies across a range of perceptual tasks have demonstrated the effect of covert attention on visual performance and perception.[29-32] Covert attentional allocation can also be attracted transiently in an automatic fashion by sudden, salient stimuli such as a spot of light flashed briefly in the visual periphery.[33] For human observers, it is hard or impossible to ignore transient cues, even when they are known to be irrelevant.[34,35]

Contrast sensitivity is a basic performance parameter of visual systems and therefore well suited to study the effect of attention on visual information processing. In addition, automatic attention captured by the short presentation of a peripheral cue, can increase the apparent contrast of subsequently presented gratings.[35,36]

In humans, noninvasive cortical stimulation techniques have been used to influence the excitability of cortical tissues and to investigate the functions of cortical regions. The most well-known are transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS). Transcranial alternating current stimulation (tACS) in external brain stimulation is a new technique. It aims to interfere with ongoing oscillations in the brain. It has been shown to improve implicit motor learning with 10 Hz stimulation of the motor cortex[37] and to interact with processes in the visual cortex in a frequency-dependent manner.[38,39]

In this study, we hypothetized that alternating current in the gamma range applied to the primary visual cortex interferes with neural synchronization thus changing the effect of attention on contrast perception. We carried out two experiments using a four-alternative forced-choice detection task to determine the effect of attention and electric stimulation on contrast detection thresholds for stimuli placed at four different distances to a cued location. Our results document a significant influence of 60 Hz tACS on contrast-discrimination thresholds, whereas contrast sensitivity was unaffected.

Methods and materials

Subjects

Twenty healthy subjects (nine women; 21-32 years old, mean age: 25.8 $\pm$ 6.2) participated in the studies. All had normal or corrected-to-normal vision. Subjects were interviewed to exclude volunteers with any history of neurologic or psychologic disorders, metallic implants, drug, or alcohol abuse. None of the subjects took regular or acute medication. All the participants gave informed written consent and all the experiments were approved by the Ethics Committee of the University of Göttingen, and conformed to the Declaration of Helsinki.

Apparatus

tACS

A battery-driven Eldith DC-stimulator Plus (NeuroConn GmbH, Ilmenau, Germany) was used with conductive-rubber electrodes, placed in saline-soaked sponges. The size of the electrode placed over Oz (in accordance with the international 10-20 EEG system) was 4×4 cm, whereas the reference electrode over Cz had a size of 7×4 cm. The electrodes were fixed with rubber bands. The electrical stimulation was sinusoidal with a current intensity of 1500 μA. Using this current intensity the maximum current density at the Oz electrode was 93,75 μA/cm^2, which is below the safety limits accepted for tDCS.[40] Because of the larger electrode size current density was 53.57 μA/cm^2 at the Cz position. Three stimulation frequencies 40, 60,