Transcranial alternating current stimulation strengthens learning of color-orientation associations

Yinghua Liu[1,2], Kohitij Kar[1,2], & Bart Krekelberg[1]

[1] Center for Molecular and Behavioral Neuroscience, Rutgers University, Newark, NJ, USA
[2] Behavioral and Neural Sciences Graduate Program, Rutgers University, Newark, NJ, USA

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Introduction

tCS modulates cognition

- tCS has been found to augment cognitive functions in various domains including memory, decision making, language, and cognitive aging[1,2,3].

- The neural mechanisms that generate and sustain tCS effects are still poorly understood.

tACS attenuates motion adaptation

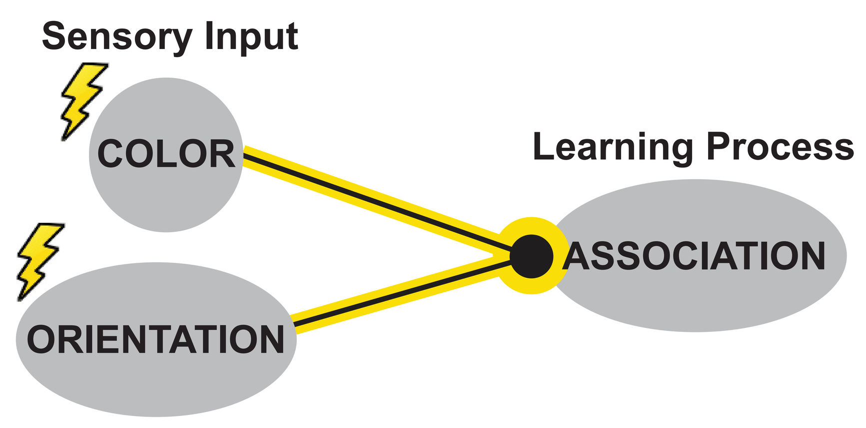
- tACS (10 Hz, 0.5 mA) over the motion area attenuated short-term visual motion adaptation in psychophysics[4], single-unit recordings[5], and fMRI[6].

Hypothesis

- Reduced sensory adaptation increases sensory responses.

- Stronger sensory responses increase Hebbian synaptic modification.

- Increased synaptic modification strengthens learning.



Methods

Experiment I: color-orientation association

- Investigated how tACS affected learning of color-orientation association using a McCollough effect (ME) paradigm.

- ME is an orientation-contingent color aftereffect that associates colors and orientations from perceptual experience[7].

- It is long-lasting - can persist for hours, days, and weeks[8]

- Suggests a mechanism that stores and sustains a color-orientation association across time; a low level form of long term memory

- Primary visual cortex likely plays an important role in the ME[9]

Experiment II: orientation adaptation

- Investigated how tACS affected orientation adaptation using a tilt aftereffect (TAE) paradigm.

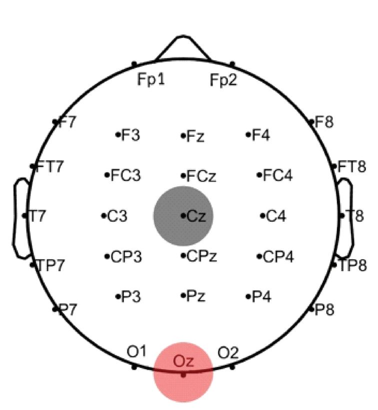
- TAE is the transient shift in orientation perception caused by prolonged exposure to one adapting orientation.

Stimulation Parameters

- Electrode positioning: Cz and Oz

- Target area of stimulation: V1

- Current: AC, amplitude of 0.5 mA at 50 Hz

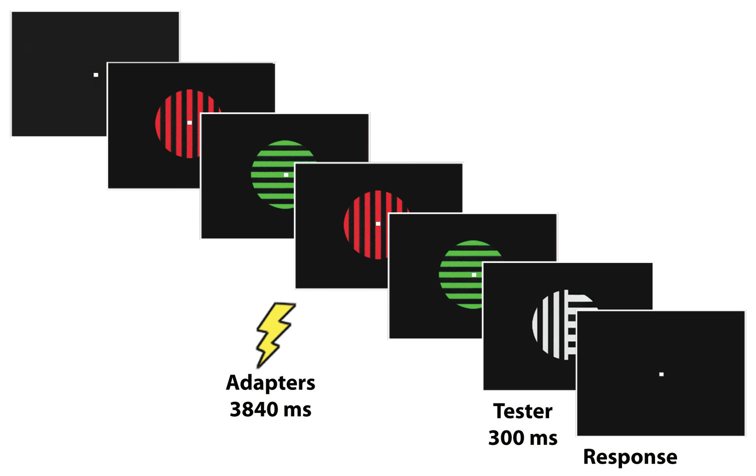


Effect of tACS on color-orientation association

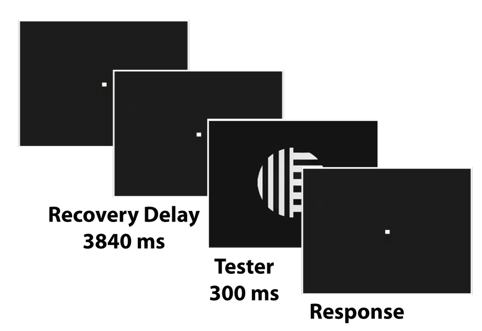
We used the McCollough Effect to quantify the learning of a color-orientation association with and without application of tACS.

Conditions tACS vs. no-tACS

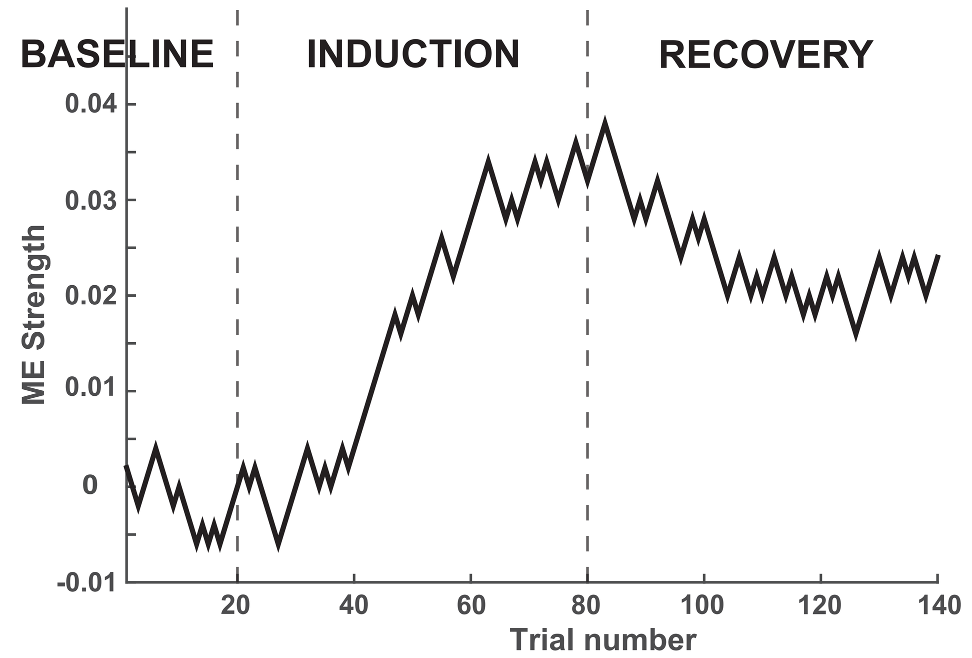
Induction paradigm



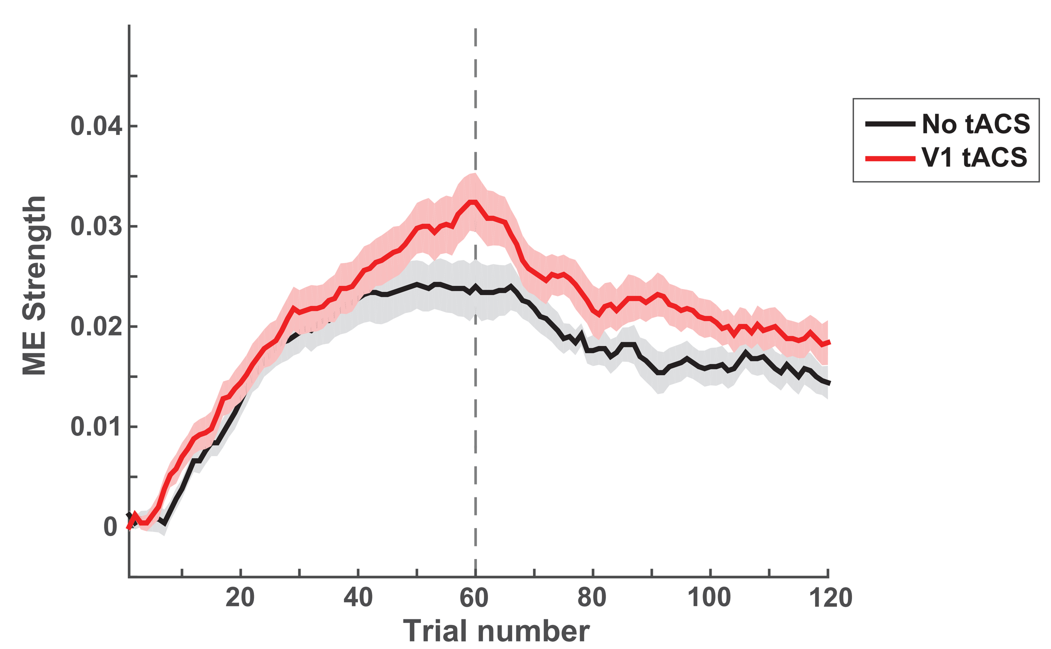
Recovery paradigm



The induction and recovery of ME in one session



Group Results (N=10)



- no-tACS condition: the induction of the ME saturated within a few minutes.

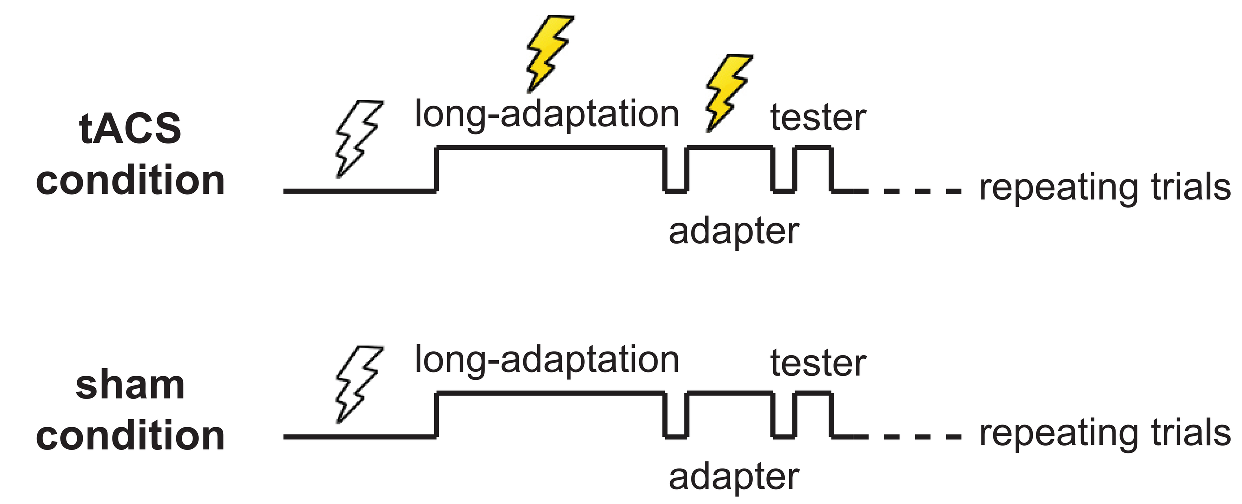
- tACS condition: no saturation was observed.

- The induced ME was significantly larger in the tACS condition compared to the no-tACS condition.

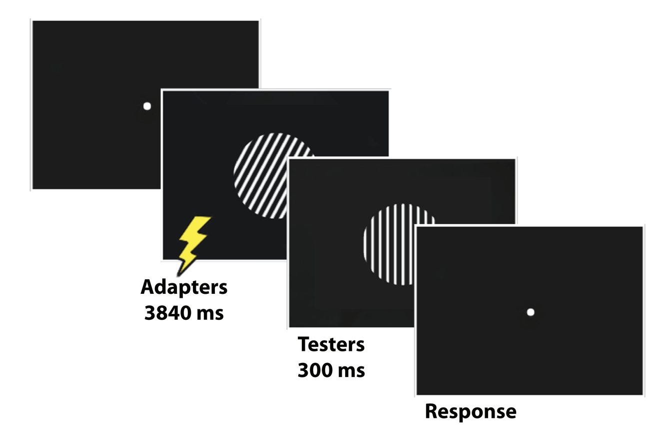
Effect of tACS on orientation adaptation

We quantified orientation adaptation using the tilt aftereffect with and without application of tACS.

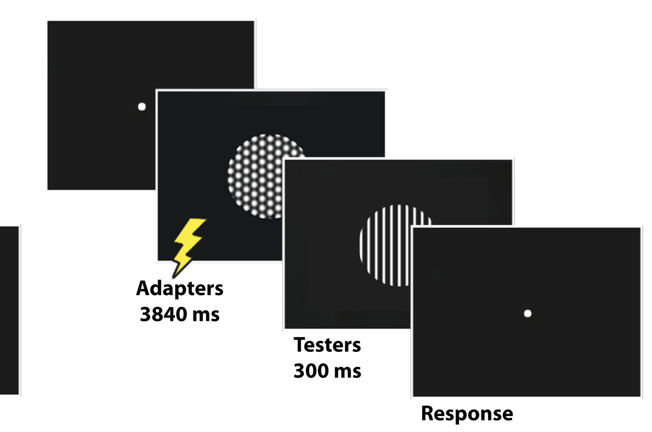
Conditions tACS vs. sham × adaptation vs. non-adaptation



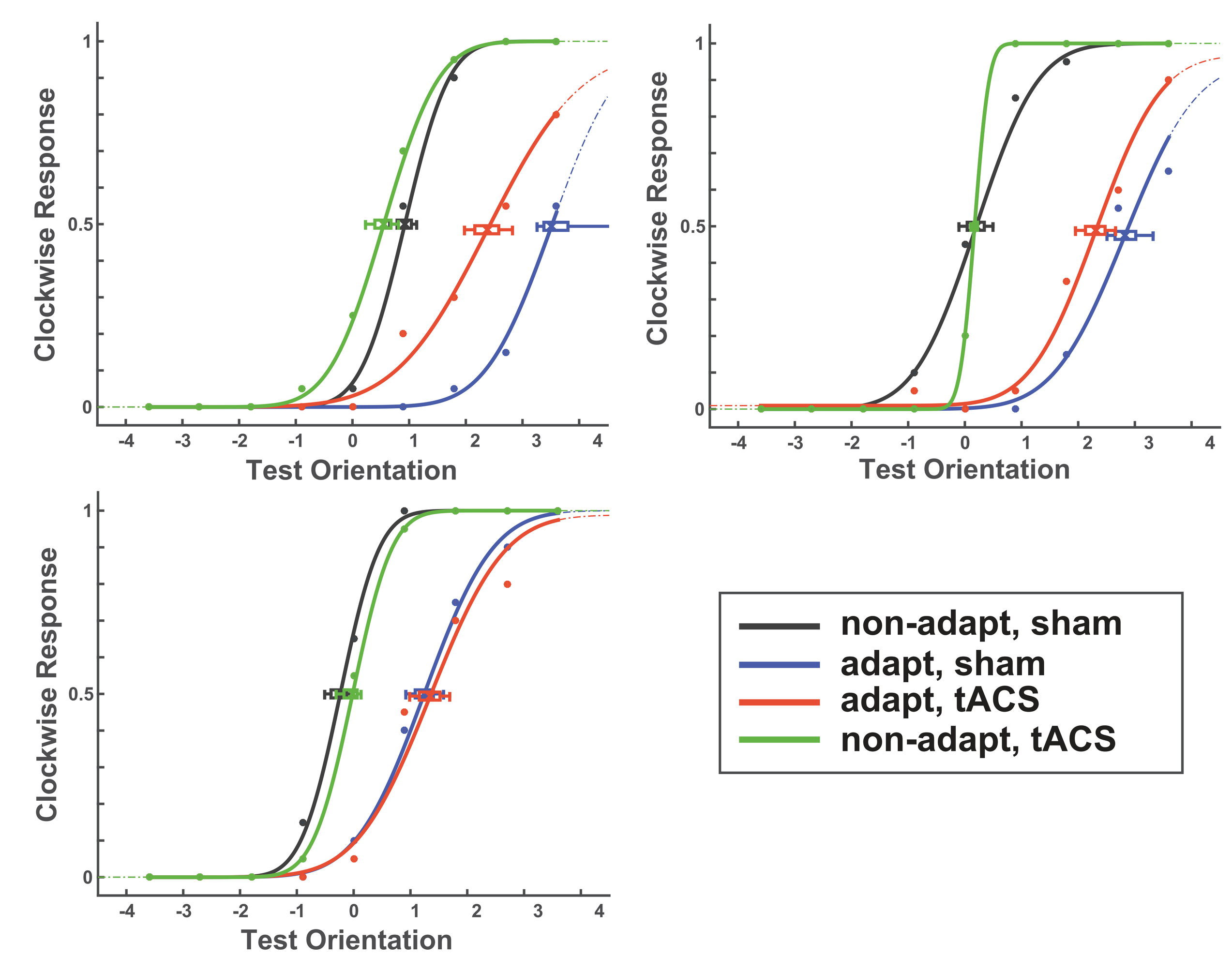
Adaptation paradigm



Non-adaptation paradigm



Preliminary results from individual subjects



- We fitted a cumulative Gaussian psychometric functions to subjects' responses and calculated the point of subjective equality across conditions.

- All subjects had a TAE.

- tACS attenuated the TAE in 2 out of 3 subjects.

Conclusions

- tACS over V1 increased the McCollough Effect demonstrating an improved learning of a color-orientation association.

- tACS over V1 reduced orientation adaptation.
This extends previous similar findings on motion adaptation.

- Results supported our hypothesized mechanism where reduced sensory adaptation by tACS leads to stronger input to neural populations that detect the conjunction of orientation and color, and thus enhances the learning of the color-orientation association.

- Results lay the groundwork for future experiments that will further test this hypothesis using behavioral experiments and electrophysiological recordings in macaque V1.

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Contact: yinghua@vision.rutgers.edu