The Causal Role of Alpha Oscillations in Selection

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Abstract

Alpha oscillations, or brain waves with a frequency between 8-12 Hz, are a neural correlate of attentional selection. Correlational studies show increases and decreases in alpha-band activity are associated with the suppression of irrelevant information and processing of relevant information respectively, but it is unclear how alpha oscillations relate specifically to these distractor suppression and target enhancement mechanisms. We manipulated alpha levels in the posterior parietal cortex with transcranial alternating current stimulation (tACS) while participants completed a color change detection task with a variable number of distractors and targets. Our results showed that alpha tACS enhanced working memory capacity in a distractor-absent condition while having no effect in distractor-present conditions. Alpha tACS also had no effect on modulating distractor filtering ability. This contributes causal evidence that alpha supports target enhancement, not distractor suppression, in the debate about alpha's role in attention.

The Causal Role of Alpha Oscillations in Selection

Selective attention, or the process of directing awareness to relevant stimuli while ignoring irrelevant stimuli, is vital to our ability to process the overwhelming amounts of information we face at any instant. When people experience attentional deficits, it can impact a host of cognitive processes including memory. For example, difficulty with suppressing irrelevant information seems to contribute to working memory (WM) impairments in older adults (Blair et al., 2011) and in clinical populations like those with schizophrenia (Becske et al., 2022). It would therefore be beneficial to understand the neurocognitive bases of attention to develop treatments and research methods.

One neural correlate of attention are alpha oscillations, or brain waves with a frequency between 8-12 Hz prominent in scalp electroencephalography (EEG) recordings (Berger, 1929). While their specific role is heavily debated, alpha power has an inverse relationship with neural activity, meaning low and high alpha power correlates with increased or suppressed neural firing respectively (Haegens et al., 2011; Laufs et al., 2003). Already, there is evidence that modulating alpha-band activity can improve attention in older populations (Borghini et al., 2018). Through examining the causal function of alpha oscillations in visual attention, this study will contribute to understanding how such treatments work, ways to improve them, and potentially developing diagnostic and research methods that use alpha oscillations as an index of attention.

Alpha Oscillations and Attentional Selection

One of the earliest theories to explain alpha's inverse relationship with neural activity was that alpha-band activity reflects visual attentional state, where decreases in alpha oscillation amplitude are associated with the expectation or presence of visual stimuli while increases in amplitude occur in the absence of stimuli (Adrian & Matthews, 1934). Since then, alpha oscillations have been implicated in many cognitive functions in addition to attention including awareness (Benwell et al., 2017; Gallotto et al., 2017), short-term memory (Jensen et al., 2002; Sauseng et al., 2009), and long-term memory (Klimesch, 1999). It is possible that alpha oscillations index more than one of these cognitive mechanisms, but it is also possible that alpha oscillations measure only one function that happens to be related to all these other mechanisms. One function candidate for the latter is attentional selection, or when attention selects which stimuli gets processed (Woodman et al., 2021).

Theories of visual attention propose that attention potentially works like a spatial spotlight, where attention acts as a spotlight focusing on a portion of the visual field (Posner & Cohen, 1984). Stimuli within this area are then preferentially processed relative to those outside the area. This is evident in the phenomenon where when participants receive an incorrect cue about where target stimuli will be, reaction time increases because participants must first shift their attention from the incorrect location to the correct one before responding. Numerous studies demonstrate alpha oscillations are similarly sensitive to spatial information (Worden et al., 2000; Kelly et al., 2006; Thut et al., 2006; Rihs et al., 2009; Sauseng et al., 2009). For example, in Worden and colleagues' study (2000), participants received an arrow cue indicating whether targets would appear to the left or right of a central fixation point and had to subsequently make orientation and motion-direction judgments about the targets. EEG recordings showed increased alpha activity in posterior brain regions on the side of the brain contralateral to the side where they expected targets to appear. Since brain hemispheres process visual stimuli located in the contralateral visual hemifield, these results suggest alpha oscillations increased in the side of the brain processing information from the irrelevant side.

While alpha oscillations relate to stimuli location, they do not seem to relate to other stimuli features. To illustrate, when Bae and Luck (2018) had participants memorize stimuli orientations and locations, the participants' sustained EEG recordings carried information about stimulus orientation regardless of stimulus location while alpha oscillations only reflected information about location. Furthermore, studies that vary the time between cue and stimuli presentation (Fukuda et al., 2016) or present the cue after stimuli presentation (Schneider et al., 2019) demonstrate that alpha oscillations primarily reflect participant responses to cues and not the stimuli themselves.

If alpha oscillations were involved in memory, one would expect them to carry information about the stimuli beyond location such as orientation. The absence of such results provides evidence for alpha oscillations' role in modulating attention over other cognitive functions like memory. Attention is closely related to memory since the things people pay attention to affect what gets encoded and retrieved from memory (Souza et al., 2016; Vogel et al., 2005), so it is unsurprising that alpha oscillations often correlate with memory performance. However, these findings that alpha oscillations only relate to spatial information suggest alpha activity primarily reflects attention and only correlates with other cognitive functions due to those functions' connections with attention.

Distractor Suppression Versus Target Enhancement

Selective attention occurs through a combination of target enhancement and distractor suppression. Even though alpha oscillations reflect attention, it remains unclear how they correspond specifically with these two processes. Target enhancement is when the stimuli of interest are enhanced compared to distractors and neutral stimuli while distractor suppression occurs when distractors are inhibited more than targets and neutral stimuli. While there is evidence that these two functions occur through independent mechanisms, studies often do not confirm this or recognize the possibility that distractor suppression is an automatic effect of target enhancement (Schneider et al., 2021). As such, it is necessary to investigate which mechanism alpha oscillations specifically relate to when examining its causal relationship with attention.

Some studies find that alpha activity strongly reflects distractor suppression (Jensen et al., 2012; Händel et al., 2011). On the other hand, there is evidence that alpha oscillations respond to targets even when there are no distractors present and do not respond to cues about distractor location, suggesting that alpha oscillations are related to target enhancement (Noonan et al., 2016; Rihs et al., 2007). It is also possible that distractor suppression and target enhancement are linked, where decreasing alpha power in one hemisphere for target enhancement automatically increases alpha activity in the other. Since studies often do not measure the effect of varying target and distractor presentation independent of each other, we cannot conclude how alpha oscillations relate to selective attention processes (Foster & Awh, 2019; Schneider et al., 2021). Furthermore, the correlational design of most of these studies means it is not possible to make conclusions about directionality and causality. Finding a causal relationship would require manipulating alpha oscillations and observing subsequent behavioral changes.

Transcranial Alternating Current Stimulation

One method to manipulate alpha oscillations is with transcranial alternating current stimulation (tACS). This is a relatively new form of noninvasive brain stimulation that sends weak, sinusoidal electric currents to the brain via an active electrode over the brain region of interest and a reference electrode over a neutral location (Herrmann et al., 2013). By adjusting the frequency of these currents, tACS can entrain endogenous brain waves of matching frequencies. In other words, naturally occurring rhythmic brain activity synchronizes in frequency and phase with the external stimulation (Battleday et al., 2014). This recruits a greater number of neurons than usual to fire at a specific frequency, thereby increasing the power of the frequency band. Compared to other brain stimulation methods, such as the more studied transcranial magnetic stimulation, tACS does not provide as strong or as focalized stimulation. However, there is still evidence that tACS can increase endogenous alpha power relative to sham stimulation (Zaehle et al., 2010) and affect performance on cognitive tasks (Helfrich et al., 2014).

Measuring Attention With WM

One way to measure how manipulating alpha oscillations with tACS affects attention is through WM performance. WM is a temporary memory store that maintains and manipulates the task-relevant information necessary for ongoing tasks (Baddeley & Hitch, 1974; Cowan, 2001). It is closely related to attention; representations of targets in WM help direct attention (Downing, 2000) while the things people attend to, both external stimuli and internal memory representations, affect what gets maintained in WM (Souza et al., 2016; Vogel et al., 2005). WM performance can thus provide insight into attention. For example, by examining how many stimuli participants stored in WM, Vogel et al. (2005) found that participants with lower WM capacity were also the ones who struggled to filter out irrelevant stimuli effectively. Similarly, assuming that alpha's relationship to spatial information but not other target stimuli features **(**Bae & Luck, 2018; Worden et al., 2000; Fukuda et al., 2016; Schneider et al., 2019) means it reflects attention rather than WM mechanisms, comparing WM performance under different alpha levels will help us determine the causal role of alpha oscillations in attention.

The Current Study

Studies investigating the role of alpha oscillations thus far have largely relied on correlational methods such as brain imaging. Those that did manipulate alpha oscillations often varied target and distractor stimuli simultaneously, making it difficult to draw conclusions as to whether alpha oscillations relate to distractor suppression or target enhancement. We plan to use tACS to manipulate alpha oscillations and identify the causal role it plays in attention. Specifically, our research question is whether alpha oscillations in the right posterior parietal cortex (PPC) represent the suppression of task irrelevant distractors or the enhancement of target representations. Through manipulating target and distractor presentation in the current experimental design, we hope to make this distinction.

We have two hypotheses. One, alpha oscillations perform distractor suppression and have no function in target enhancement. In this case, we should see task performance change following alpha tACS only on trials with distractors. Alternatively, our second hypothesis is that alpha oscillations perform target enhancement and not distractor suppression. If this is true, then overall performance should change under alpha tACS as the number of objects people attend to changes, but this should not differ based on whether or not distractors are presented.

Methods

Participants

We recruited 20 Vanderbilt University undergraduate students (11 females) through Vanderbilt's SONA system. Participants were at least 18 years old (*M* = 20.35, *SD* = 2.67) and had normal or corrected-to-normal vision, no colorblindness, no history of self-reported neuropsychiatric disorders, and no metal implants in their heads. They were compensated for their time with partial course credit or a total of $55 for all three sessions.

Materials

We provided participants with informed consent forms containing information about the study's purpose and procedures, benefits and risks of participating, confidentiality, and how to contact the researchers. Participants also completed a questionnaire (Appendix A) to screen for metal or electronic devices in the body and other potential risks to undergoing transcranial electrical stimulation (Ko, 2021). After the study, participants completed a questionnaire (Appendix B) about any side effects they experienced (Reinhart et al., 2017).

We presented stimuli and collected responses using MATLAB (The MathWorks Inc.) and the Psychophysics Toolbox (Brainard, 1997) on a Windows computer. Stimuli were 1.3° tall and appeared in randomly generated positions at least 1° vertically and 2.4° horizontally away from each other on each trial. They were one of seven highly discriminable colors (black, white, red, yellow, green, blue, and violet) with no two stimuli ever being the same color per trial.

tACS was delivered through a Soterix Medical 1x1 transcranial Electrical Stimulation (1x1-tES) device and a pair of 35 cm^2 (5x7 cm) conductive rubber electrodes encased in saline-soaked sponges secured on the scalp and face with headbands.

Design

We used a within-subject design where each participant performed a visual change detection task under all three stimulation conditions (alpha, theta, or sham) across three separate days. A variable number of distractors (0, 2, or 4) and targets (2, 4, 6) combined to create seven different set size conditions (2T0D, 2T2D, 2T4D, 4T0D, 4T2D, 4T4D, 6T) that also varied within-subject. Between-subject independent variables included the order of stimulation conditions and which key (F or J) indicated a change versus no-change response. These were counterbalanced across participants. The dependent variable was visual WM capacity, quantified by Cowan's K (Cowan, 2001).

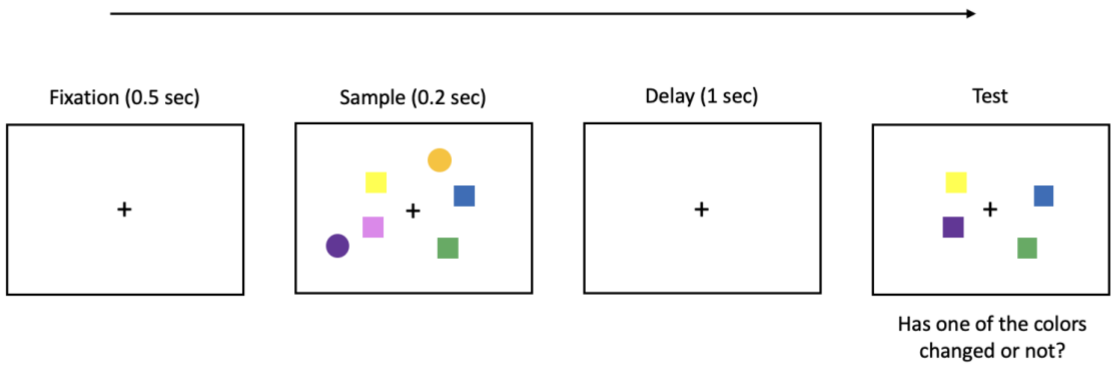
Procedure

After participants provided informed consent and completed the screening questionnaire, we secured tACS electrodes (see tACS section below) on participants and applied stimulation continuously for the remainder of the study (during both practice and formal tasks). Participants sat about 60 cm in front of the computer screen in a small room while a researcher monitored their progress and stimulation contact quality outside.

The change detection task required participants to determine if one of the targets (solid-colored squares) changed in color while ignoring a variable number of distractors (solid-colored circles). We instructed participants to view stimuli using their peripheral vision while fixating on a central fixation cross (1.5°) that was always present on screen. Targets and distractors appeared on both sides of the central fixation cross. Each trial began with 500 msec of blank screen followed by 200 msec of one of the seven set size conditions. After a 1000 msec delay, the targets reappeared with one square in a different color half the time and unchanged the other half of the time. The stimuli remained on screen until the participant responded by pressing "F" for change and "J" for no change or vice versa (Figure 1).

Figure 1

Example of 4 Target 2 Distractor (4T2D) Condition



Participants completed a practice block (20 trials) until they reached at least 0.75 accuracy before beginning the formal task. During the formal task, each set size condition occurred 50 times in random order for a total of 350 trials that took around 20-30 minutes to complete. Afterwards, participants completed a post-experiment questionnaire about side effects. All participants returned for second and third sessions 2-8 days after the previous visit to repeat the task under a different stimulation condition.

tACS

Alpha and theta tACS were the active stimulation conditions, where alpha tACS was the condition of interest and theta tACS served as a positive control. Sham tACS served as the negative control (Riddle et al., 2020). The active electrode was placed at P4 (right PPC) of the standard 10-20 EEG system (Oostenveld & Praamstra, 2001) for alpha and sham stimulation conditions, and it was placed at F3 (left frontal cortex) for theta stimulation. The reference electrode was placed on participants' contralateral cheek. For alpha and theta stimulation conditions, we set the 1x1-tES device to apply sinusoidal stimulation at a frequency of 9 Hz or 4 Hz respectively with a current strength of 1000 μA. We slightly decreased the current strength if participants experienced discomfort, but this happened rarely. To blind participants to the stimulation condition, the procedure for sham stimulation was identical to alpha stimulation except the sham switch was turned on; the stimulator would ramp up to 1000 μA and immediately ramp back down to 0 Hz.

Data Analysis

We excluded data from participants who did not complete all three sessions or did not perform significantly above chance (0.75 accuracy). We first calculated participants' WM capacity per set size as measured by Cowan's K (K = Set Size * [Hit rate - False Alarm rate]). To check for filtering efficiency, or the ability to suppress irrelevant stimuli from entering visual WM, we compared performance when distractors were present versus not present. Specifically, we averaged participants' filtering efficiency in 2T2D and 2T4D conditions (Filtering Efficiency = ([4T-2T2D]/[4T-2T] + [4T-2T4D]/[4T-2T])/2)). A score of 0 suggested inefficient filtering while a score of 1 indicated efficient filtering (Vogel et al., 2005). To normalize WM capacity and filtering efficiency measures, we subtracted the WM capacity and filtering efficiency parameters of the sham condition from those of the active stimulation conditions (alpha and theta stimulation).

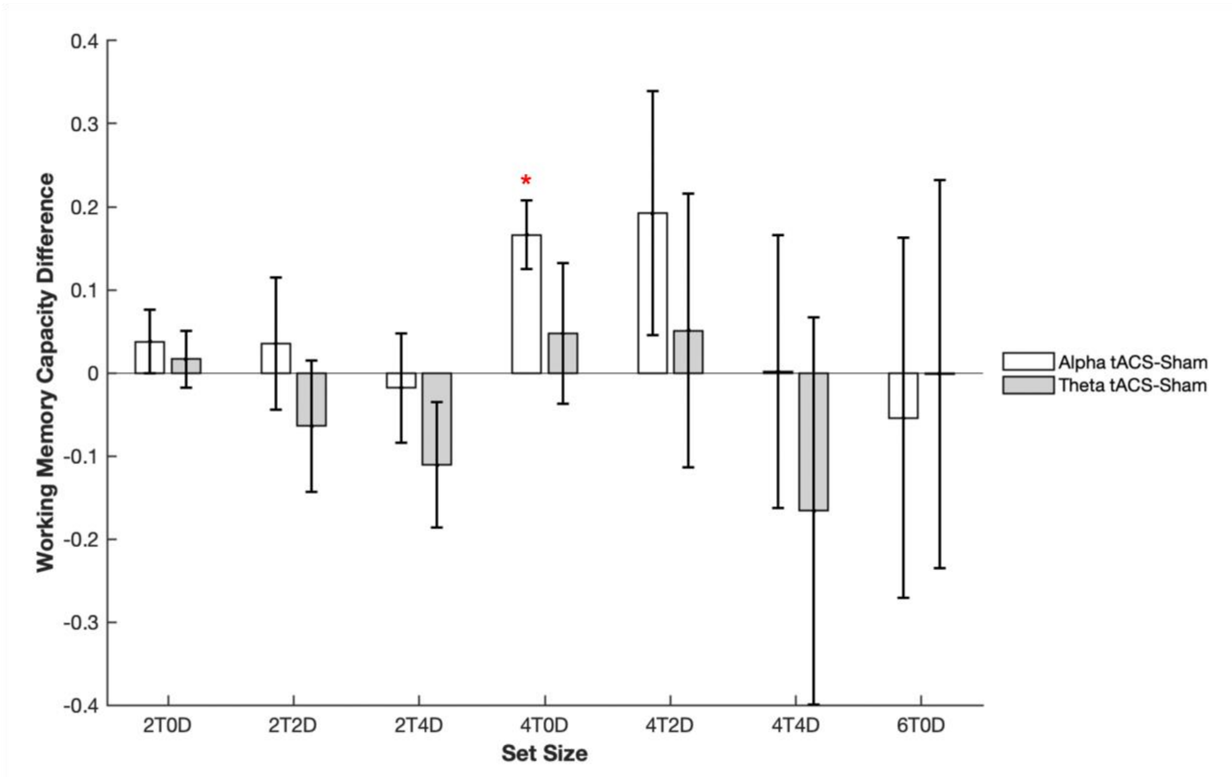
Results

Alpha tACS Over Right PPC Selectively Enhanced WM Capacity

Paired-sample *t*-tests showed that alpha tACS over the right PPC selectively enhanced the normalized WM capacity value compared to zeroes only at set size 4T0D, $t(19) = -3.94$, $p = .018$ (passing the Bonferroni multiple comparison correction) and not at any other set sizes, $|t|$s < 3.94, *p*s > .218 (Figure 2). We found no significant tACS effect with theta stimulation at any set size, $|t|$s < 1.44, *p*s > .167. These results confirm that any evidence for enhanced memory capacity via tACS is specific to alpha-band stimulation.

Figure 2

Alpha and Theta tACS Effect on WM Capacity



Note. Alpha tACS over the right PPC significantly increased WM capacity selectively in the 4T0D condition.

* p = 0.018 with Bonferroni correction, p = 0.00087 before correction

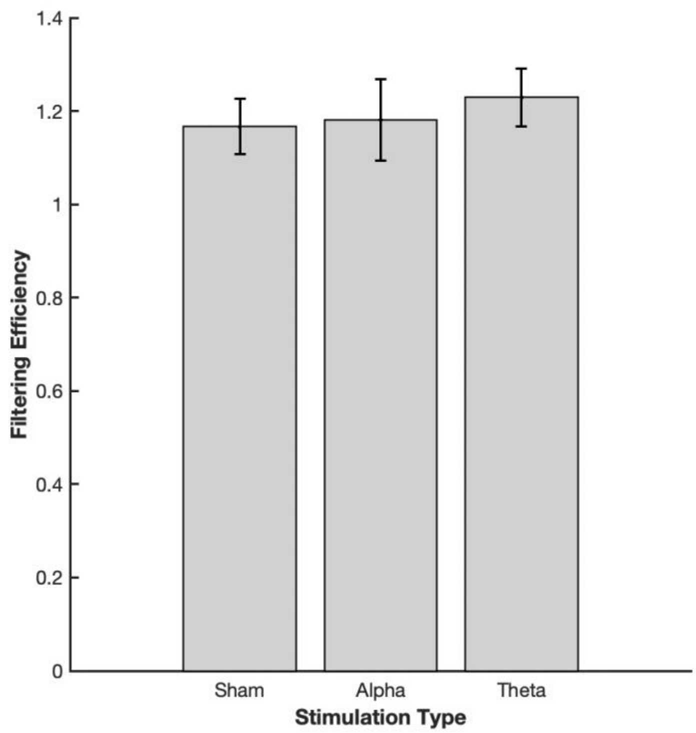
Null Stimulation Effect on Filtering Efficiency

To examine whether different types of stimulation modulate distractor filtering, the normalized filtering efficiency measures were compared against zeroes using paired-sample *t*-tests for each set size condition. We found that neither alpha stimulation nor theta stimulation influenced the normalized filtering efficiency value compared to zeroes, $t(19) = -0.25$, $p = .802$, BF = 0.239; $t(19) = -1.05$, $p = .307$, BF = 0.377 for alpha and theta stimulation respectively

(Figure 3). These results confirm that neither alpha nor theta stimulation in the current study had an effect on modulating distractor filtering ability.

Figure 3

tACS Effect on Filtering Efficiency



Note. No significant modulation was found on filtering efficiency under any stimulation.

Post-Experiment Questionnaires Reveal Similar Feeling Between Stimulation Conditions

We blinded participants to the stimulation condition they underwent each session to avoid an expectation effect. To test whether participants could tell the difference between distinct stimulation types, we ran a one-way repeated measures ANOVA on participants' post-experiment questionnaire reports. We assigned the responses from "very mild" to "extremely" with values 1-5. A "no" response was coded as 0.

There was a significant difference in responses across the stimulation conditions only for Question 6, where participants rated whether they experienced sensations like pain, tingling, itching, or burning under the electrodes during or after stimulation, $F(2, 38) = 5.69$, $p = .007$, $\eta_p^2 = .230$; subjects reported more of these sensations following the two active stimulation conditions than sham. Pairwise comparisons for this question with Bonferroni corrected p values showed a significant difference in responses between sham and alpha stimulation, $t(19) = -3.45$, $p = .006$, and sham and theta stimulation, $t(19) = -3.14$, $p = .010$, but not between alpha and theta stimulation, $t(19) = -0.08$, $p = .934$.

Differences in responses approached marginal significance when participants rated level of discomfort (Visual Analog Scale (VAS) Question 1), $F(2, 38) = 3.10$, $p = .072$ and level of attention and fatigue (VAS Question 2), $F(2, 38) = 3.25$, $p = .050$. Consistent with the responses for Question 6, pairwise comparisons for VAS Question 1 revealed no significant difference between alpha and theta stimulation, $t = -1.90$, $p = .073$. There was a significant difference between alpha and theta stimulation for VAS Question 2, $t = 2.64$, $p = .032$ (Bonferroni corrected), but there was no significant difference between alpha and sham stimulation, $t = 0.18$, $p = .857$. Furthermore, like VAS Question 2, Questions 2 and 5 also asked about concentration and fatigue respectively, but there was no significant difference in responses across the stimulation conditions, $F(2, 38) = 0.76$, $p = .477$; $F(2, 38) = 1.30$, $p = .285$ respectively.

These results demonstrate that even though participants sometimes felt different sensations across the three stimulation conditions, they could not tell the difference between alpha and the other two stimulation conditions, ruling out the possibility that the alpha stimulation effect found in the current experiment is caused by an expectation effect.

Discussion

The aim of this study was to examine the causal role of alpha oscillations in visual selective attention. To see whether alpha-band activity selectively reflects distractor suppression or target enhancement, we applied three stimulation conditions (alpha, theta, and sham) using tACS while participants completed a WM change detection task with varying numbers of distractors and targets. We found that there was a measurable enhancement of WM capacity from alpha tACS, specifically in the 4T0D condition. The other stimulation conditions had no significant effect on WM capacity. Additionally, no stimulation condition significantly modulated distractor filtering efficiency.

Alpha Oscillations Play a Causal Role in WM Retention, Not Distractor Suppression

Our results that alpha stimulation in the current experiment enhanced target representations and not distractor suppression contribute to the debate regarding whether alpha reflects distractor suppression or WM retention (maintenance). Studies supporting the former found greater alpha power in the hemifield ipsilateral to target items (the side that processes distractors) than contralateral that increased as memory load increased (Worden et al., 2000; Kelly et al., 2006; Thut et al., 2006; Rihs et al., 2009; Sauseng et al., 2009). However, the correlational nature of these studies makes it difficult to draw causal conclusions. Given that there is evidence for decreases in alpha activity in the hemisphere contralateral to target items (the side that processes targets), the changes in alpha activity can also be interpreted to reflect target enhancement (Sauseng et al., 2005). Further support for this view lies in how when participants received cues for target or distractor locations, their alpha activity only tracked the cued location of targets and not distractors (Noonan et al., 2016). Alpha activity also appears to increase with WM set size in the absence of distractors, further opposing the view that alpha activity is related to distractor suppression (Fukuda et al., 2015).

We found that stimulating alpha-band activity selectively increased WM capacity in a distractor-absent condition while having no effect in distractor-present conditions. This is consistent with a recent review that found inconclusive evidence for alpha oscillations' role in distractor suppression and proposed alpha-band activity might instead reflect target enhancement (Foster & Awh, 2019). Thus, our findings add to support for the view that alpha supports WM representation, not distractor suppression, in the debate about alpha's role in attention.

WM Capacity Improved Only Under Alpha tACS in Set Size 4T0D

It is currently unclear why alpha tACS significantly affected WM capacity only in the 4T0D condition. One potential explanation is that this set size is a unique informational load that benefits from alpha stimulation while stimulation does not help with set sizes containing less or more information. In lower load conditions (2T0D), it might have been so easy for participants to remember the two targets that there was no room to increase WM capacity. Meanwhile, in the higher load conditions (6T0D), the task may have been too difficult given that the visual WM capacity limit for young adults is 3-5 items (Cowan 2010). For distractor-present conditions, alpha stimulation might not have been able to reduce the impact of distractors on targets, thus resulting in no enhancement effect.

Another possible explanation for the significant positive result at set size 4T0D is that it was due to noise. Given that we parametrically manipulated the set size, we know from subjects' performance that the task was most difficult at set size of 6 targets. Thus, it is possible that our sample had noise that afforded significance when it was not a reliable result. Additional research is needed to address this. To this end, we are currently conducting a follow-up experiment to replicate our findings that alpha tACS affects WM capacity in set sizes with 4 targets and to investigate whether the alpha stimulation effect is hemisphere specific. In the experiment, we stimulate participants' left and right PPC with alpha tACS. We use the same change detection task as the present study but present objects laterally. Participants receive cues for which side targets will appear. In the hemifield opposite of targets, we manipulate what objects are presented to see whether alpha stimulation modulates WM performance by influencing the processing of the uncued objects.

Although most previous studies about oscillations have been correlational, there have been some that found an effect of alpha and theta tACS on visual WM unlike our current results. Methodological differences could account for these conflicting findings. While studies like Jaušovec et al. (2014) found tACS applied at frequencies adjusted for participants' individual alpha peak frequency improved WM storage capacity, we applied tACS at the same frequency for all participants. In addition to frequency, multiple studies have shown that phase differences between tACS and participants' endogenous oscillations can affect stimulation efficacy. For example, Chen et al. (2023) developed a way to correct for phase differences and found that anti-phase alpha tACS significantly lowered WM performance relative to in-phase tACS. They found no difference in WM performance between anti-phase alpha tACS and random-phase tACS, the latter of which probably reflects the type of stimulation in our study. Similarly, previous research shows in-phase theta tACS improved RT in a visual memory task while anti-phase theta tACS worsened performance (Polanía et al., 2012). It is possible that variability in how the frequency and phase of tACS interacted with participants' individual differences contributed to noise in our study. Future studies could record EEG to confirm assumptions about how tACS is affecting endogenous oscillations and personalize stimulation settings for each participant.

Differences in participants' age and health could have also contributed to discrepancies between findings in the current study and those in previous literature. For example, Borghini et al. (2018) found alpha tACS over the PPC improved WM performance in older adults. Meanwhile, Thompson et al. (2021) applied similar methods on younger adults, like the participants of the present study, but found no effect. Studies have also found improved WM performance under tACS in clinical populations like schizophrenia patients (Chang et al., 2021; Sreeraj et al., 2019). In contrast, the participants in our study were all young, healthy adults. This potential interaction between participant characteristics and stimulation efficacy is in line with a recent review by Al Qasem et al. (2022), which reported that tACS effects are more pronounced in low baseline performers like older adults and those with neurodegenerative diseases. Meanwhile, WM performance results remain inconsistent in studies like the current experiment where participants are young and healthy.

Importance of the Present Study

Complex cognitive processes like visual selective attention require multiple brain regions that serve different functions to transiently work together. Neural oscillations are a promising answer to how brains solve this dynamic coordination problem (Fries, 2009). Oscillations reflect cycles of when neurons have higher and lower excitability, or when neurons are more or less likely to spike respectively. Given this, researchers propose that when the oscillations of neuronal populations synchronize in frequency, the times during which they are excitable align, and this enhances communication between these areas (Fries, 2005). Studying neuronal oscillations is thus important to improving our understanding of how disparate parts of the brain coordinate to perform a variety of tasks.

Out of the frequency bands, alpha oscillations stand out as many event-related potential components relevant to measuring visual selective attention have most of their power in this band (Makeig et al., 2002). Correlational studies find that increases and decreases in alpha-band activity relate to distractor suppression and target enhancement respectively, but it remains unclear how alpha oscillations specifically affect attentional selection. Although the present study found increasing alpha-band activity increased WM capacity, likely through target enhancement, these results are inconclusive. We hope that through our current and future research, this will prove definitive.

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Appendix A

SCREENING QUESTIONNAIRE FOR TRANSCRANIAL ELECTRICAL STIMULATION (TES)

		YES	NO
1	Do you have metal (except titanium) or electronic implants in the brain/skull (e.g., splinters, fragments, clips, cochlear implants, deep brain stimulation etc.)? If yes, please specify the type of metal and the location ______________________________		
2	Do you have metal or any electronic device at other sites in your body, such as a cardiac pacemaker or traumatic metallic residual fragments? If yes, please specify the device and the location ______________________________		
3	Did you ever have surgical procedures involving your head or spinal cord? If yes, please specify the locations ______________________________		
4	Have you ever had a head trauma followed by impairment of consciousness?		
5	Do you have skin problems, such as dermatitis, psoriasis or eczema? If yes, please specify the location ______________________________		
6	Do you have epilepsy or have you ever had convulsions, a seizure?		
7	Did you ever have fainting spells or syncope?		
8	Are you pregnant or is there any chance that you might be?		
9	Are you taking any medications? If yes, please specify: ______________________________		
10	Did you ever undergo transcranial electric or magnetic stimulation in the past? If yes, were there any adverse events? Please specify: ______________________________		

An affirmative answer to one or more of questions do not represent an absolute contraindication to TES, but the risk-benefit ratio should be carefully balanced by the Principal Investigator of the research project or by the responsible (treating) physician.

Name ______________________ Surname ________________________

Date ____________________ Signature ___________________________

Appendix B

Subject ID:_______________________ Date:_____________________

Directions

Please circle the appropriate answers to the following questions regarding your experience in this research study, adding information if necessary. Your responses will be kept in the strictest of confidence.

1. Did you experience any feelings of a headache? Yes No

If so, please rate the severity.

Very Mild Mild Moderate Severe Extremely

2. Did you experience any difficulty concentrating? Yes No

Is so, please rate the severity

Very Mild Mild Moderate Severe Extremely

3. Did you experience any change in mood? Yes No

Is so, please rate the severity

Very Mild Mild Moderate Severe Extremely

4. Did you experience any change in vision? Yes No

Is so, please rate the severity

Very Mild Mild Moderate Severe Extremely

5. Did you experience any fatigue? Yes No

Is so, please rate the severity

Very Mild Mild Moderate Severe Extremely

6. Did you experience any sensations like pain, tingling, itching, or burning under the electrodes during or after stimulation? Yes No

Is so, please rate the severity

Very Mild Mild Moderate Severe Extremely

Visual Analog Scales (VAS)

1. Please rate your level of discomfort (1 = no discomfort, 10 = extreme discomfort)?

1 2 3 4 5 6 7 8 9 10

2. Please rate your level of attention and fatigue (1 = least attentive/most fatigue, 10 = most attentive/least fatigue

1 2 3 4 5 6 7 8 9 10