Investigating the neural basis of cognitive control using delta and theta Transcranial Magnetic Stimulation

Morgan A. Brown[1], Dylan (Wu) Li[1], Justin Riddle[1]
[1]Florida State Univ., Tallahassee, FL

Study Rationale

- Cognitive control is the capacity to flexibly adapt behavior and execute rapid decision-making based on internal goals and environmental demands[1]
- Hierarchical cognitive control extends this capacity by managing multiple levels of context – where immediate cues are further modulated by a multi-stage set of rules to produce behavior that aligns with these complex, multilevel rules[2]
- Distinct oscillatory dynamics, specifically the frontoparietal regions, underlie execution of complex cognitive tasks[1,3]
- Delta-frequency oscillatory patterns associated with higher-order rule abstraction, whereas theta-frequency oscillatory patterns facilitate the management of set size
- Neuroimaging findings convey greater abstraction demand the mid-dorsolateral prefrontal cortex (dlPFC), while increased set size activates the dorsal premotor area (PMd)[1]
- Transcranial magnetic stimulation (TMS), a non-invasive brain stimulation technique, endogenously modulates neural activity

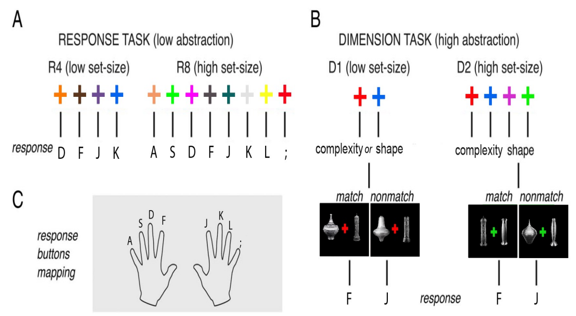
Hypothesis and Study Aims

- Analyze the behavioral impacts of delta rTMS on the mid-dlPFC and theta rTMS on the PMd
- Delta-frequency stimulation of the mid-dlPFC enhances abstraction performance, while theta-frequency stimulation of the PMd improves set-size management

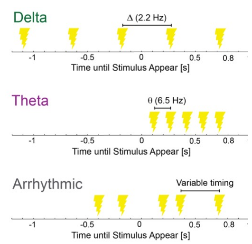
What we did

- 9 Undergraduate students at FSU (6 female) aged 18-24 (M = 19.55, SD = 1.81)
- High-density (96-channel) EEG acquired with 4 channel EMG (vertical and horizonal eyes)
- Screening and Baseline
  - All participants screened for TMS eligibility
  - EEG baseline while completing the Hierarchical Cognitive Control (HCC) Task
  - Motor thresholding to determine endogenous amplitude at which to deliver stimulation
- Experimental Sessions
  - Rhythmic TMS (rTMS) to either mid-dlPFC or PMd with concurrent EEG during HCC Task
- TMS Conditions
  - Delta, theta, and arrhythmic stimulation patterns were randomly intermixed in sessions 2 & 3.

Hierarchical Cognitive Control Task

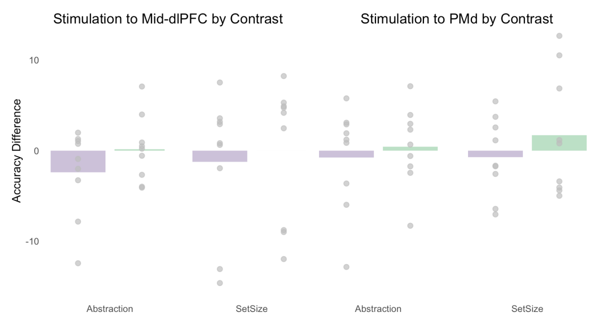


Stimulation Conditions



- Participants received randomized stimulation in one of three conditions—delta, theta, and arrhythmic
- Participants completed 12 blocks, each comprising of 48 trials, for a total of 576 trials per TMS session
- Across 12 blocks, each stimulation condition was paired equally with each of the 4 task conditions to ensure balanced exposure

Behavioral Results



Theta stimulation to PMd slightly increased performance for higher set-size conditions while delta stimulation to mid-dlPFC decreased performance on higher-abstraction conditions

What we found

- Early behavioral analyses observe considerable individual variability in performance across set-size and abstraction conditions following delta-theta rTMS, with no consistent trend identifiable yet
- Theta stimulation aligns with theoretical expectations, whereas delta stimulation produces an unanticipated inverse effect on performance.

What we expect to find

- Delta-frequency rTMS applied to the mid-dlPFC is expected to facilitate higher-order abstraction processes, whereas theta-frequency rTMS targeting the PMd is anticipated to enhance cognitive efficiency in set-size management tasks.
- Arrhythmic stimulation will not significantly alter performance or oscillatory activity and explore cross-frequency effects (delta to PMd, theta to mid-dlPFC) on cognitive control, which will not be significant
- Time frequency analyses expected to show targeted rTMS will enhance corresponding oscillatory activity (delta in mid-dlPFC, theta in PMd), aligning with behavioral improvements.

Limitations and Future Directions

Limitations

- Small sample size due to currently ongoing recruitment
- Data has not yet been cleaned to filter off-target stimulation trials from participant movement

Future directions

- Conduct time frequency analyses on EEG data to determine the neural mechanisms underpinning cognitive performance
- Assess functional connectivity of the mid-dlPFC and PMd using neuroimaging

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References

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For any questions regarding the poster, please email Morgan Brown: mbrown36@fsu.edu

To learn more about the Riddle lab: https://www.theriddlelab.org/