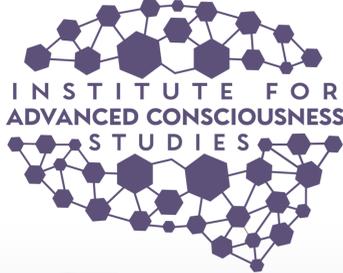


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Towards Enhancing Meditation with Focused Ultrasound Neuromodulation in Expert Meditators

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SHORT ON TIME? HERE'S THE SUMMARY

Our overarching goal is to reliably induce deep and beneficial states of meditation with neuromodulation. Here, we target three candidate regions of the brain: Posterior cingulate cortex (PCC), Caudate, and Insula via non-invasive focused ultrasound (FUS) neuromodulation while probing the quality of meditation in experts. Caudate seems most effective.

INTRODUCTION

- Consistent meditation benefits those with affective disorders¹, however aspiring practitioners often struggle to maintain a regular practice².
- Focused ultrasound (FUS) neuromodulation can be used to *non-invasively* target brain regions (e.g., those related to achieving mindfulness) with unmatched⁴ (millimeter scale) spatial precision³ *anywhere in the brain*.

PCC

Caudate

Insula

Simulations of FUS energy distribution

- The **PCC**, a key component of the default mode network (DMN), is linked to self-referential thinking⁵ and "effortless awareness"⁶. Its activity is reduced during mindful meditation⁷.
- Caudate** damage may result in "Athymhormia," a condition described as mental emptiness with loss of motor and affective motivation but without anxiety or pain⁸. There exist clear similarities between this and mindfulness.
- The **Insula** appears to mediate emotional regulation and interception⁹ and may play a particular role in particular meditative techniques (e.g., body scanning)¹⁰.

AIM

Does FUS disruption of the PCC, Insula, or Caudate result in changes in meditative depth, intensity, physiology, or subjective quality during a 1-hour meditation in expert meditators?

We predict:

- Increase in depth** in PCC and Caudate condition compared to sham
- Decrease in depth** in Insula condition compared to sham
- Increase in subjective intensity** (any change in subjectivity) in all stimulation conditions compared to sham

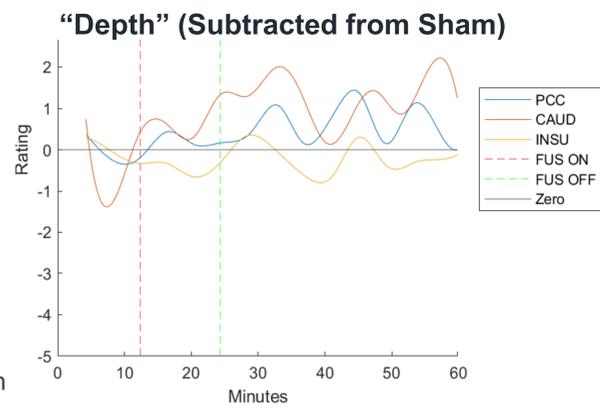
RESULTS

(Highly Preliminary n = 3)

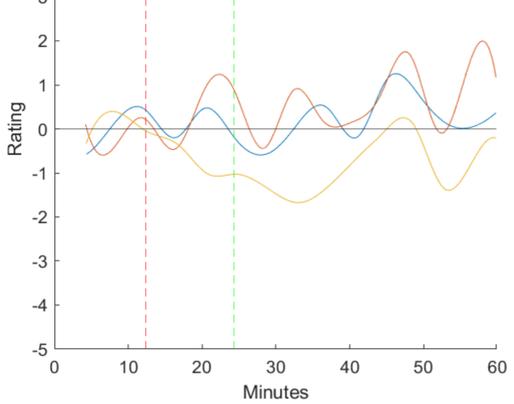
NOTE: Report scale is from 1-5 and subtracted from sham

On average:

- Increase in meditative depth during and following caudate stimulation.
- Similar, but smaller and more variable effects during and following PCC stimulation
- Little to no effect of Insula stimulation



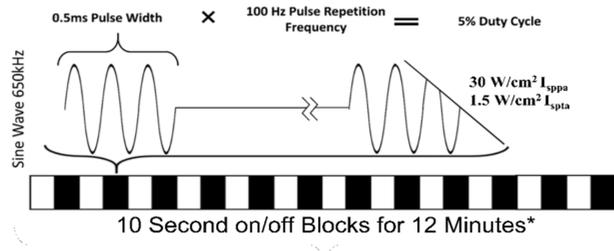
"Intensity" (Subtracted from Sham)



On average:

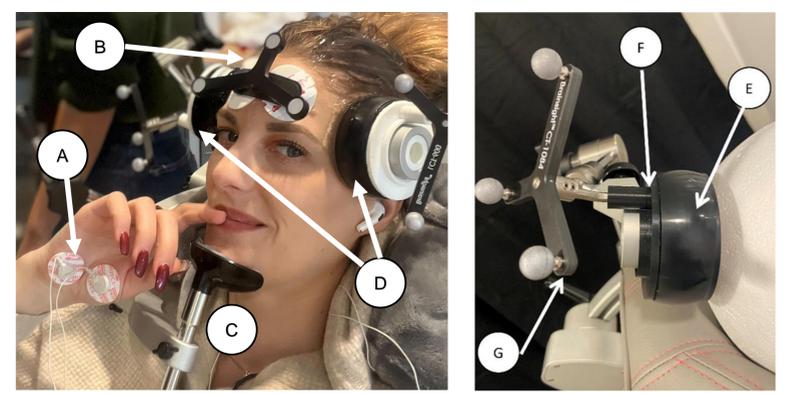
- Increase in intensity during and following caudate stimulation
- Reduced intensity in insula condition (related to interoceptive function of insula?)
- What "Intensity" means here is probed in high-dimensional post-questionnaire.

METHOD

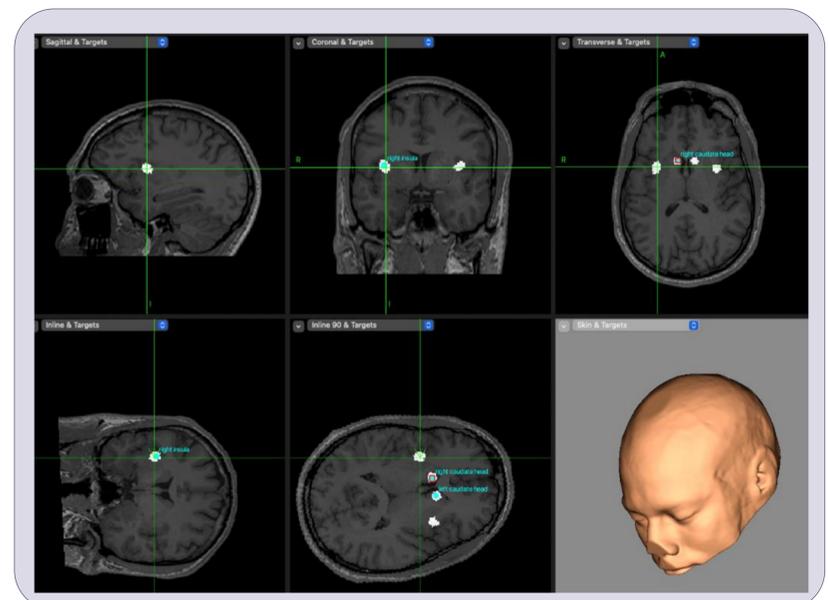


- Expert Vipassana meditators (n=3; 10+ years experience including on retreats) participated in 4 total sessions to compare the effects of ultrasound stimulation applied (for 12 minutes) to 3 targets + 1 sham (one site per session) during a 1- hour long vipassana meditation
- "Online" (During Meditation/FUS) Variables Measured:**
 - Self-reported meditative "depth" and subjective "intensity" (probed every ~4 minutes)
 - Physiological changes (GSR, EMG, HR, RR)
- "Offline" (After Meditation/FUS) Variables Measured:**
 - Pre and post-meditation questionnaire to assess altered subjectivity induced by stimulation

Rest	Pre-FUS Meditation	FUS Meditation (Target A,B,C, or Sham)	Post-FUS Meditation
5min	12min	12min	36min



- A: Physiological Sensors** – measures heart rate, respiration, GSR, EMG
- B: Subject Tracker** – allows for real-time tracking of subject head/brain position
- D/E: Brainsonix Transducer (source of ultrasound)** – Emits ultrasound in a cone that tapers to a focal point of high energy over a target region
- F: 3D printed custom-made attachment** – Integrates Brainsight with FUS
- G: Transducer-tracking fiducial** – Used to position center of ultrasound transducer over target region inside the brain



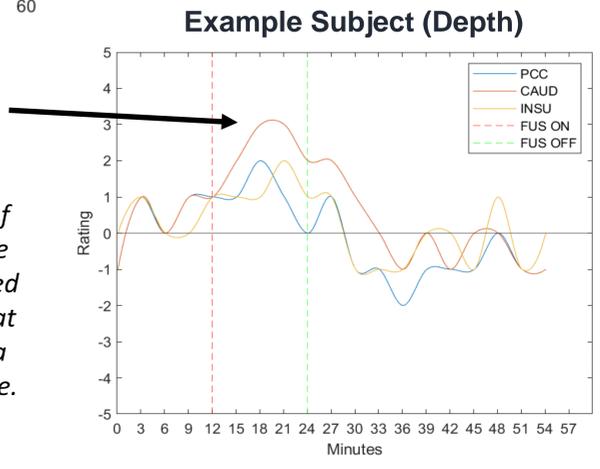
Brainsight Neuronavigation:

- Infrared (IR) camera detects real-time position of transducer in relation to subject MRI scan

About Caudate Stimulation:

"Likelihood of it being sham: 0%"

"This was it! After about 5 minutes of stimulation, I felt like I was just in the meditative state and I didn't even need to try. I didn't even have thoughts that I needed to ward off in order to get a glimpse of the nothingness experience. I just was."



CONCLUSIONS

- Average increases in reported depth during Caudate (esp.) and PCC stimulation **compared to a sham control**. Depth in Insula condition equal to or slightly below sham. Intensity reduced during insula condition.
- Our early results (emphasizing individual subject report) are consistent with effects on subjectivity during meditation and the potential of FUS as a method for inducing deep states of mindfulness

ACKNOWLEDGEMENTS

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