

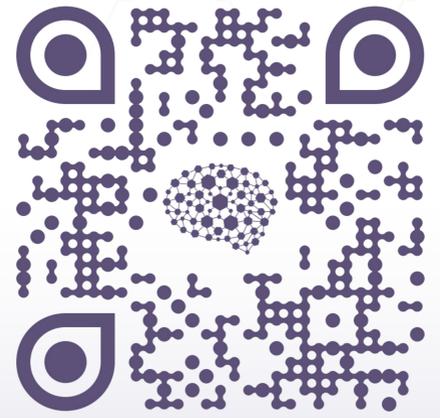
Effective Deepening of Meditative-States with Focused Ultrasound Stimulation and its Moderation by Prior Experience

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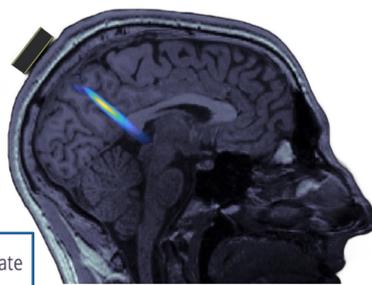
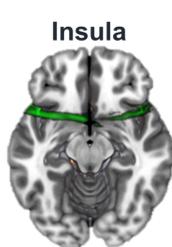
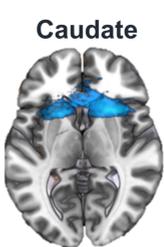
SHORT ON TIME? HERE'S THE SUMMARY

Focused ultrasound was utilized to precisely disrupt the Posterior cingulate cortex, head of the Caudate Nucleus, and the Ventral-Anterior Insula during 1-hour meditation sessions in 12 expert and 12 novice Vipassana meditators, while assessing changes in meditative depth and subjective intensity compared to baseline. Results indicate **PCC and Caudate-FUS effectively induce greater meditative depth in experts** versus a validated Sham-FUS procedure, with similar subjective intensity changes. Crucially, **these effects were absent in trained novices**, highlighting the importance of experience in modulating FUS-induced meditative states.



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INTRODUCTION



The **Posterior Cingulate Cortex (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.

Focused Ultrasound Stimulation (FUS)

- > Works by *painlessly and safely* passing ultrasound waves (the same used in ultrasound imaging) through the skull and concentrating them on a single point in the brain (Dell'Italia et al. 2022)
- > Use in humans is *less than a decade old* (Bystritsky et al. 2011).
- > **Safety & Efficacy** is (now) well-validated (Dell'Italia et al. 2022)
- > Very **Precise & Versatile**: i.e., can selectively target small regions *anywhere* in the brain, including our targets (Cain et al., 2021).

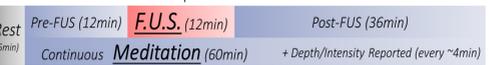
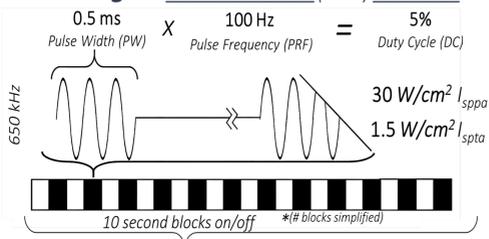
(Vipassana) Meditation and It's Benefits

- > Benefits—both psychological and physical—for health and well-being (Roberts et al., 2017)
- > Aspiring practitioners experience considerable difficulty maintaining the consistent, year-long practice required (i.e., "meditative development") (Lomas et al., 2015)—even while using extant meditative-aids (e.g., mobile applications, neurofeedback) (Huberty et al., 2019).

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? In Novices?

Methods

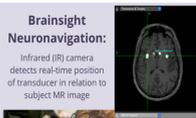
Design & Focused Ultrasound (F.U.S.) Parameters



"Online" (During Meditation/FUS) Variables:

Self-reported meditative "depth" and subjective "intensity" (probed every ~4 minutes)

Physiological changes (GSR, EMG, HR, RR)



"Offline" (After Meditation/FUS) Variables:

Pre- and post-meditation questionnaire to assess altered subjectivity induced by stimulation

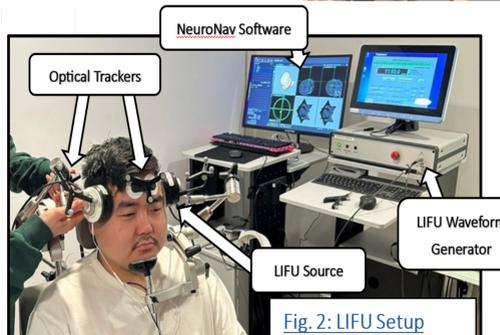
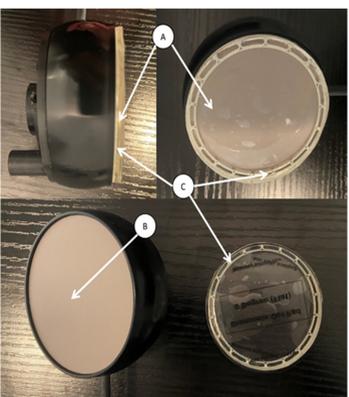


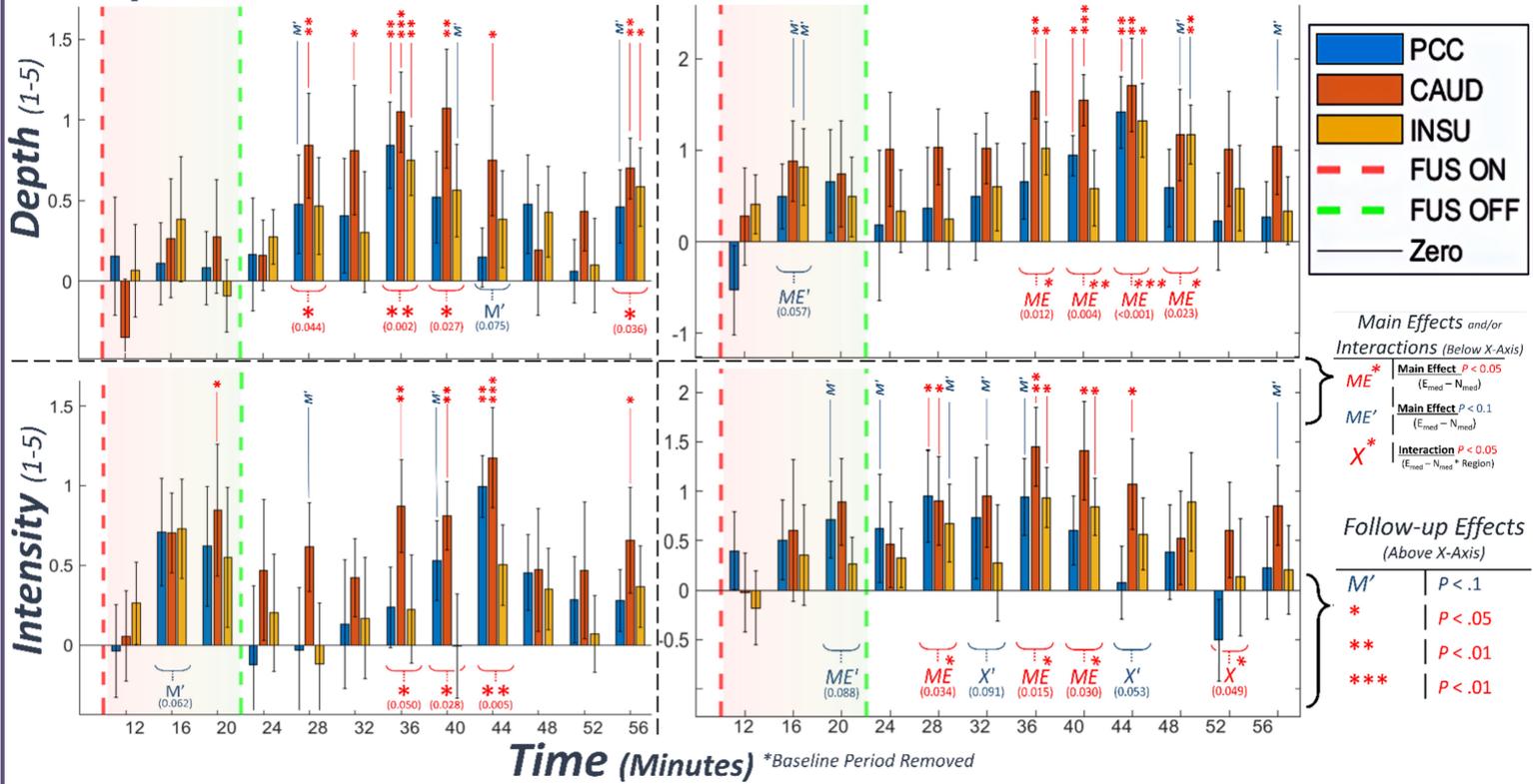
Fig. 2: LIFU Setup



"How likely was today Sham Stimulation?"
No Effect of Condition! $p > 0.05$

Self-Report During Meditation

Experts (Active vs. Sham-FUS) Experts – Novices (Sham-Normalized prior to Subtraction)



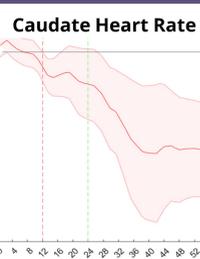
Main Effects and/or Interactions (Below X-Axis)

- ME* Main Effect $P < 0.05$ ($E_{med} - N_{med}$)
- ME' Main Effect $P < 0.1$ ($E_{med} - N_{med}$)
- X* Interaction $P < 0.05$ ($E_{med} - N_{med} \times$ Region)

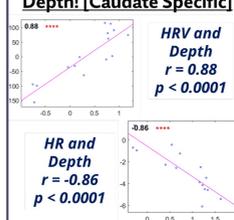
Follow-up Effects (Above X-Axis)

- M' $P < .1$
- * $P < .05$
- ** $P < .01$
- *** $P < .01$

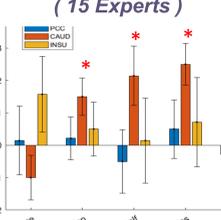
Physio Recording (CN in 15 Experts)



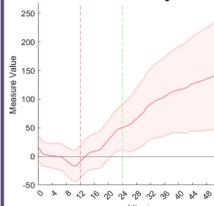
Physiology Correlates with Depth! [Caudate Specific]



Retrospective Report (15 Experts)

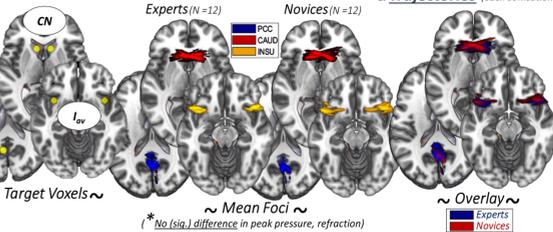


Caudate Heart Rate Variability



FUS-Simulations

FUS-simulation (Study Wide) with Pseudo-CT's (each subject) & Trajectories (each sonication)



CONCLUSIONS

Focused ultrasound holds potential as a meditative aid for increasing depth and intensity in experts, with the strongest effects following Caudate stim (CN-FUS)

CN-FUS increased HRV and decreased HR which both correlated with meditative depth reports across time

The impact of FUS may be state-dependent, with experts' refined perceptual acuity and ability to access sensitive states potentially rendering them more susceptible to stimulation-induced changes in phenomenology compared to novices.

A "therapeutic window" for this procedure may open after the very start of contemplative practice.

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