INSTITUTE FOR
ADVANCED CONSCIOUSNESS
STUDIES

Decoding Depth of Meditation:
Neurophysiological Insights from Expert Vipassana Practitioners

Reggente, N.[1], Kothe, C.[2], Nath, M.[1], Brandmeyer, T.[1,3], Hanada, G.[1,3], Simonian, N.[1,3], Mullen, S.[1,3], Mullen, T.[1,3]

[1]Institute For Advanced Consciousness Studies, Santa Monica, CA, USA | [2]Intheon, San Diego, CA, USA | [2]BrainMind, San Francisco, CA, USA

SHORT ON TIME? HERE'S THE SUMMARY

We **decoded self-reported meditative depth across two sessions (≥ 1 week between)** in expert Vipassana practitioners (n=34) using **source-localized EEG** in theta, alpha, and gamma bands along with **Heart Evoked Potential amplitudes**. Conventional EEG channel-level methods and a priori chosen brain regions failed to capture the complex, non-linear neural dynamics associated with varying meditation depths. We also introduce **"spontaneous emergence" as an ecologically valid phenomenological sampling method**, creating potential for multivariate, personalized neurofeedback.
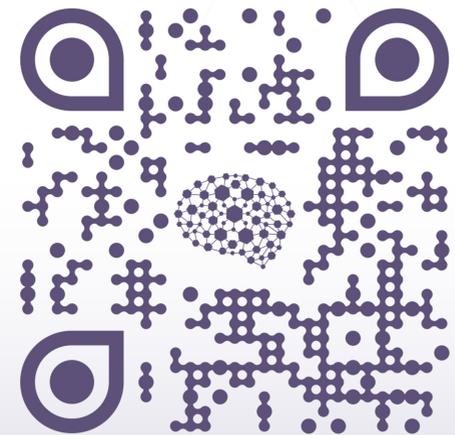
Scan the QR Code for a PDF

MOTIVATION

→ To enhance EEG specificity for meditation neurofeedback, this study explores nuances within the meditative experience, going beyond differentiating meditation from other states (e.g., mind-wandering).

→ Focusing on moment-to-moment "meditative depth" reporting in expert Vipassana practitioners, a high-dimensional, multivariate decoding approach is used to identify neural correlates of meditative gradations.

→ Given the relationship between meditation and interoceptive awareness [1], this study also examines Heart Evoked Potentials as a function of meditative depth to further elucidate psychophysiological correlates.

METHODS

→ **Expert Vipassana practitioners** (n=34; μ_experience=16.15 years, practicing μ=6.53 days/week, with μ=82.38 cumulative retreat days)

→ 160 total minutes of meditation **across 2 sessions** (≥ 1 week apart) with 2 blocks per session with **64-Channel EEG** (BrainProducts) & **Bio Peripherals** (CGX)

→ Participants rated their meditative depth (1-5 button presses; shallow to deep) since their last report and confidence (1-5; low to high) using a finger-mounted clicker in separate blocks: spontaneously upon noticing mind-wandering (**"spontaneous emergence"**) or when prompted by audio cues at ~4-minute jittered intervals (**"probe"**). For depth classification analyses, ratings with confidence ≥ 4 were included and epochs were extracted:

Previous Emergence — Depth rating pertains to here — Current Emergence

Ignored Margin (10s) | Data under consideration (variable length) | Ignored Margin (5s)

→ Multiple source estimation methods (channel-based, sLORETA, generalized eigendecomposition, and deep learning) were compared using either spectral power or connectivity features in theta, alpha, and gamma bands. Models were evaluated using leave-one-participant-out cross-validation, with mean absolute error (MAE) for the continuous 1-5 scale and area under the receiver operator curve (AUC) for the two-level scale (low: 0-2, high: 4-5) as accuracy measures.

→ For **Heart Evoked Potential** Analyses, EEG data were segmented into epochs **time-locked to the R-peak of the ECG**. One-way ANOVAs compared HEP amplitude across continual depth (1-5) and t-tests compared grouped depths (low: 1-2, high:4-5).

References: [1] Lima-Araújo, G. et al. (2022). The impact of a brief mindfulness training on interoception: a randomized controlled trial. Plos One, 17(9), e0273864. https://doi.org/10.1371/journal.pone.0273864

EEG Based Classifiers Can Decode Meditative Depth

Source Estimation Method	Measure	Continuous Depth (MAE, lower is better)	Low/High Depth (AUC, higher is better)
Channel-based (subset)	Power	1.501 +/- 0.372	0.634 +/- 0.159
	Connectivity	1.522 +/- 0.359	0.610 +/- 0.135
Channel-based (all)	Power	1.391 +/- 0.302	0.724 +/- 0.101
sLORETA	Power	1.397 +/- 0.350	0.714 +/- 0.180
	Connectivity	1.457 +/- 0.330	0.684 +/- 0.150
Gen. Eigval	Power	1.426 +/- 0.516	0.722 +/- 0.150
	Connectivity	**1.262 +/- 0.300**	0.754 +/- 0.110
Deep Learning	Power	1.289 +/- 0.292	**0.807 +/- 0.117**
	Connectivity	1.335 +/- 0.313	0.798 +/- 0.128
EEGNet	N/A	1.329 +/- 0.385	0.756 +/- 0.157

Deep learning-informed source-localized ROIs using theta, alpha, and gamma band power achieved **81% depth decoding accuracy** for high (4,5) vs. low (1,2)

Generalized Eigendecomposition-informed source-localized ROIs using theta, alpha, and gamma connectivity achieved **1.2 Mean Absolute Error** in predicting continuous depth (1-5)
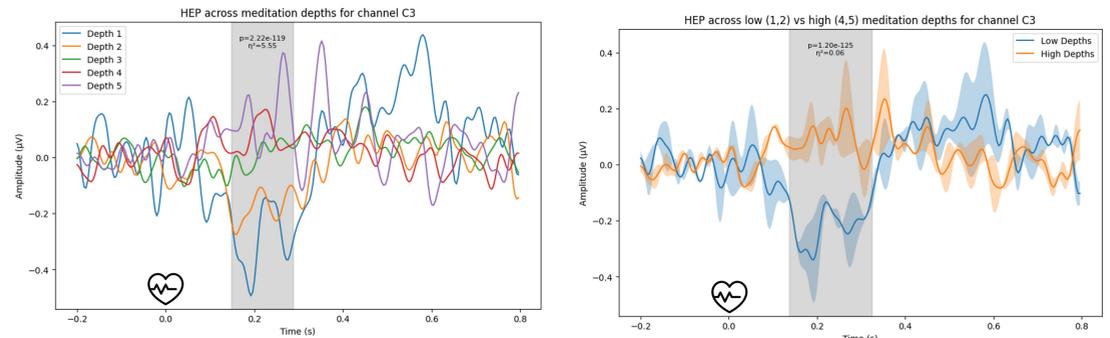
Scalp forward projections of learned EEG sources corresponding to the node connectivity weights between six spatial components estimated using the Generalized Eigendecomposition.

Theta (4-7 Hz)   **Alpha (8-12 Hz)**   **Gamma (31-42 Hz)**
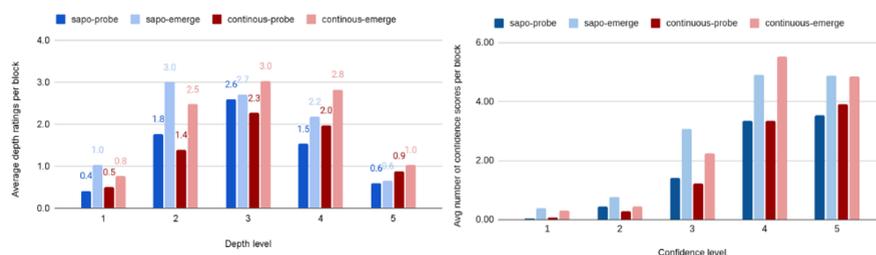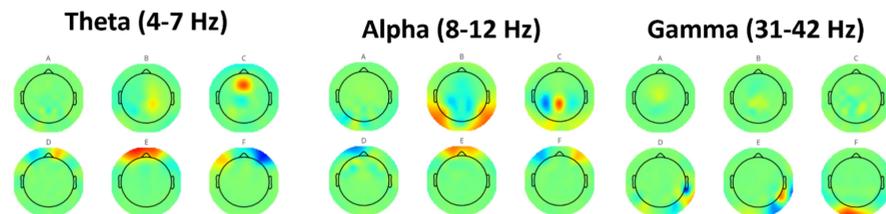
Participants provided **45% more ratings (with more confidence) in the "spontaneous emergence" blocks** with equivalent accuracy values to "probe".

Heart Evoked Potential Amplitude Increases With Meditative Depth

Is this increased sensitivity to endogenous signals a mechanism underlying the increased interoceptive awareness and well-being accompanying meditation practice?

HEP across meditation depths for channel C3

HEP across low (1,2) vs high (4,5) meditation depths for channel C3

When using HEP-amplitude data, a Random Forest classifier achieved .63 MAE (1-5) and 91% Accuracy (High vs. Low)

CONCLUSIONS

→ Source-localized EEG power, Heart Evoked Potential amplitudes, and connectivity measures outperformed conventional methods in decoding self-reported meditative depth, revealing complex neural dynamics and heart-brain interactions.

→ "Spontaneous emergence" proved to be a more ecologically valid and effective method for capturing self-reported depth compared to probing that yielded more responses and equivalent decoding accuracies.

→ Decoding meditative depth feasibility is a critical step towards developing sophisticated, **multivariate neurofeedback** for effective meditation practice

ACKNOWLEDGEMENTS