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INSTITUTE FOR ADVANCED CONSCIOUSNESS STUDIES

Heartbeat-Evoked Potentials as a Neural Marker of Meditative Depth

Nath, M.[1,2], Reggente, N.[1]

[1]Institute For Advanced Consciousness Studies, Santa Monica, CA, USA | [2]Albert Ludwig University of Freiburg, Freiburg im Breisgau, Germany

SHORT ON TIME? HERE'S THE SUMMARY

This study examined **Heartbeat Evoked Potentials (HEPs)** during meditation in expert Vipassana practitioners (n=30), revealing progressive amplitude increases **tracking self-reported meditative depth in real-time** across multiple site visits. While traditional EEG markers often reflect non-specific states like relaxation or drowsiness, HEPs capture the heart's direct influence on brain activity—a neurophysiological marker **inherently personalized to each practitioner's embodied experience**. This heart-brain coupling, robust over the C3 region, serves as a putative precise indicator of interoceptive processing, addressing a core dysfunction across mental health conditions that meditation ameliorates. The specificity of HEPs as a marker of meditative depth, combined with their accessibility via single-channel EEG, makes them **ideal for neurofeedback interventions** fostering heightened embodied awareness. By quantifying the heart's causal influence on neural signatures during meditation, this approach offers a tractable pathway toward personalized meditation training, illuminating mechanisms underlying its broad therapeutic effects.

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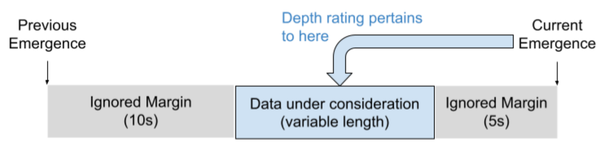
MOTIVATION

- To enhance EEG specificity for meditative states, this study moves beyond broad contrasts like meditation versus mind-wandering, instead probing **moment-to-moment shifts in meditative depth**.
- Our research group previously used deep learning to decode self-reported meditation depth from EEG signals in experienced Vipassana practitioners [1]. This work builds on that foundation with a more elegant, and interpretable approach.
- This study investigates HEPs as neurophysiological correlates of meditative gradations, revealing how **heart-brain interactions** shift with varying depths of meditation.
- Given the established link between meditation and interoceptive awareness [1], HEPs provide a physiologically grounded, individualized marker of embodied awareness, capturing how the brain responds to internal bodily rhythms.

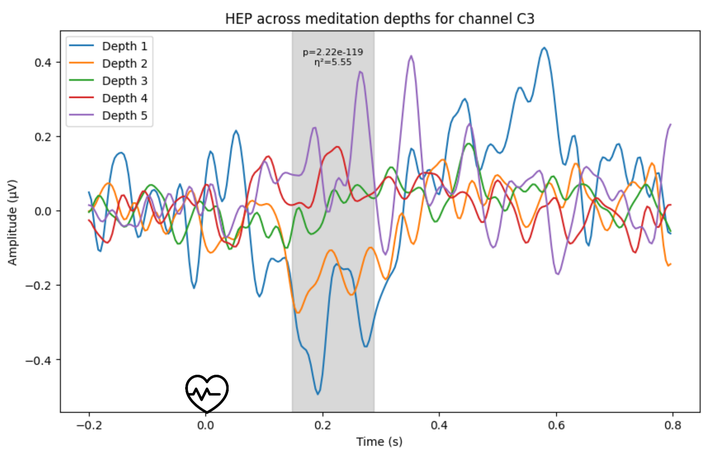
METHODS

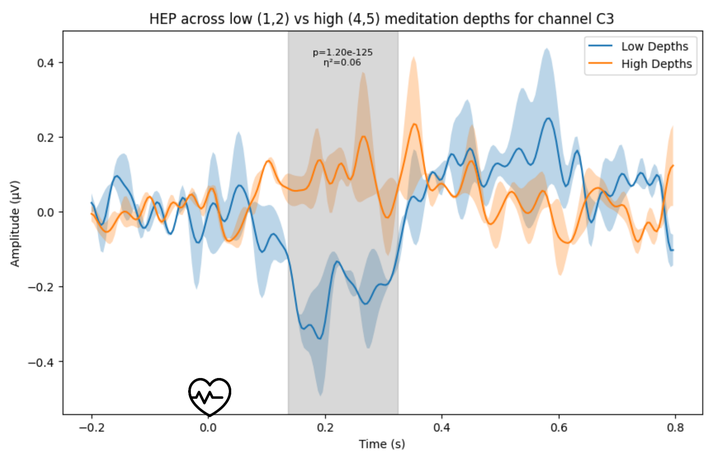
- **Expert Vi** ce=16.15 years, practicing μ=6.53 days/week, with μ=82.38 cumulative retreat days)
- 160 total minutes of meditation **across 2 sessions** (≥ 1 week apart) with 2 blocks per session with **64-Channel EEG** (BrainProducts) & **Bio Peripherals** (CGX)
- During 45-minute sessions, participants 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"**). Epochs were extracted as follows and ensured no overlap with reporting periods:

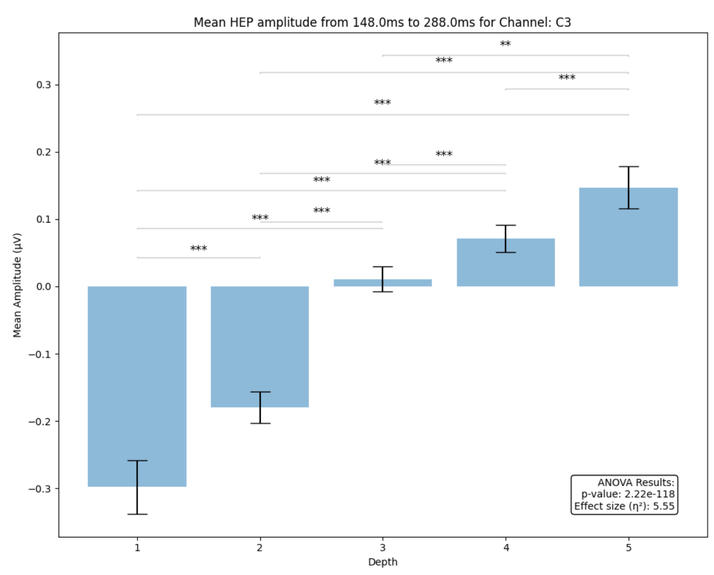


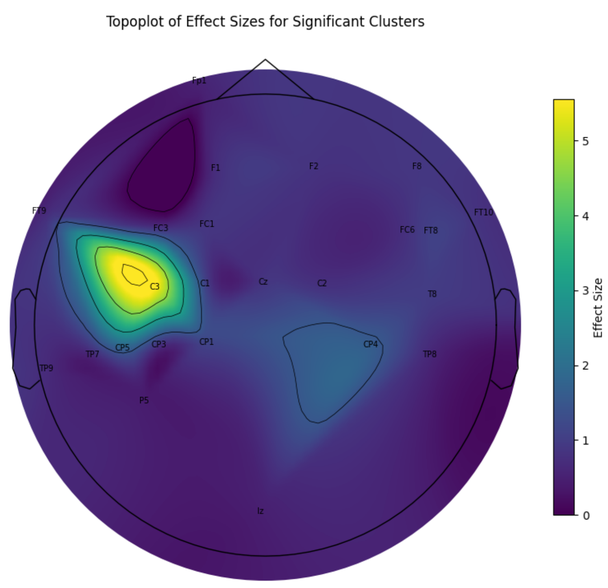
- EEG data were segmented into epochs **time-locked to the R-peak of the ECG**. Each epoch spanned from -200 ms to +800 ms relative to the R-peak.
- The EEG data were preprocessed through band-pass filtering (0.5-30 Hz), automated artifact rejection, and manual correction via independent component analysis (ICA). Baseline correction was applied using the pre-R-peak interval (-200 to 0 ms).
- HEP amplitudes across depths (1–5) were compared via one-way ANOVAs. Low (1–2) vs high (4–5) depths were tested with t-tests. **Cluster-based permutation tests** (1000 permutations) with FDR correction controlled for multiple comparisons; Tukey's HSD followed for pairwise contrasts
- Exploratory Analyses: We calculated the **HEP range** as the difference in mean HEP amplitude (channel C3, 144-288 ms) between high (4, 5) and low (1, 2) meditative depths for each participant. Mixed linear models assessed its **prediction of post-session self-reports (POMS, MEDI, TMS)**

RESULTS









C3 HEP range significantly predicted post-session metrics

- **Toronto Mindfulness Scale (TMS):** Greater HEP range → **higher Decentering** (Coef = 6.79, p = 1.25E-06).
- **Profile of Mood States (POMS):** Greater HEP range → **reduced total mood disturbance** (Coef = −2.22, p = 0.03), **increased vigor** (Coef = 2.25, p = 3.84E-23)**, and decreased fatigue** (Coef = -4.20, p = 2.28E-02)**.**
- **Meditation Depth Index (MEDI):** Greater HEP range → **lower Personal Self** (Coef = −0.31, p = 6.93E-03) and **higher Transpersonal Self** (Coef = 0.65, p = 1.00E-138).

CONCLUSIONS

- **HEPs provide a precise index of meditative depth** using minimal hardware—single-channel EEG and ECG—outperforming complex multivariate approaches[1] and enabling scalable neurofeedback applications. This provides some scientific credence to the Vedantic emphasis on refined inner attention (*shruti*) within the "cave of the heart" (*nihitam guhayam*), that is effectively suggesting **"listen to your heart"** during meditation.
- HEPs' direct link to interoceptive awareness and their suitability for real-time tracking make them ideal for enhancing meditation practices via tools like neurofeedback. Their relationship with both mindfulness depth and positive outcomes that downregulate egoic emphasis suggest a **potential marker of non-ordinary, self-transcendent experiences**.
- The specificity and responsiveness of HEPs enable precise adjustments in neurofeedback protocols, potentially improving the effectiveness of meditation training and outcomes in mindfulness-based interventions. Future research might explore how **real-time HEP feedback could guide practitioners towards interoceptive sensibility promoting states.**

References: [1] Reggente, N., Kothe, C., Brandmeyer, T., Hanada, G., Simonian, N., Mullen, S., & Mullen, T. (2024). Decoding Depth of Meditation: EEG Insights from Expert Vipassana Practitioners. *Biological Psychiatry: Global Open Science*. [2] 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

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