PORTFOLIO PROJECT · SIGNAL PROCESSING

Alpha-Band Phase-Lag as a Predictive Biomarker for TMS Optimization

*A spectral EEG feature that predicts per-subject optimal stimulation timing — **r = 0.49, p = 0.015**.*

Yarden Viktor Dejorno

ML Engineer · Brainsway Deep-TMS R&D Lab (2021–2022)

01 · THE PROBLEM

TMS therapy is a one-size-fits-all protocol — but brains aren't.

Paired Associative Stimulation (PAS) drives brain plasticity by firing two cortical sites at a precise interval (IPI). The therapeutic window is narrow — milliseconds matter.

Current practice: use one fixed IPI (typically 8 ms) across all patients. Clinical response varies widely.

THE ML QUESTION

Can we extract a per-subject feature from raw EEG that predicts their optimal stimulation parameter?

Input: multi-channel resting-state EEG (5 min, 256 Hz)

Output: scalar — predicted optimal IPI ∈ {4, 8, 16, 32 ms}

Challenge: N=24. Deep learning is out. Feature engineering is in.

02 · THE DATA

Clinical trial, 24 subjects × 9 sessions.

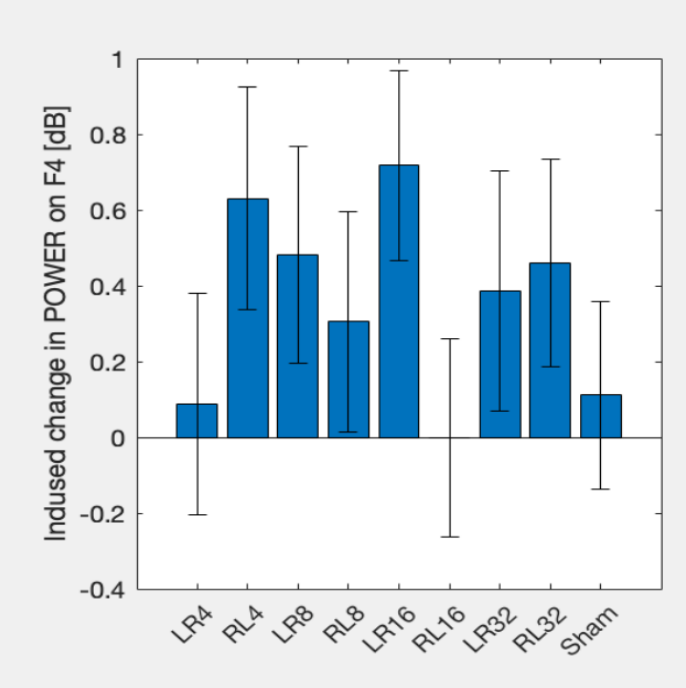
24	9×	256 Hz
Healthy participants	**Weekly sessions per subject**	**Multi-channel EEG**
Repeated-measures design	*4 IPIs × 2 directions + sham*	*Pre + post each stimulation*

Experimental design

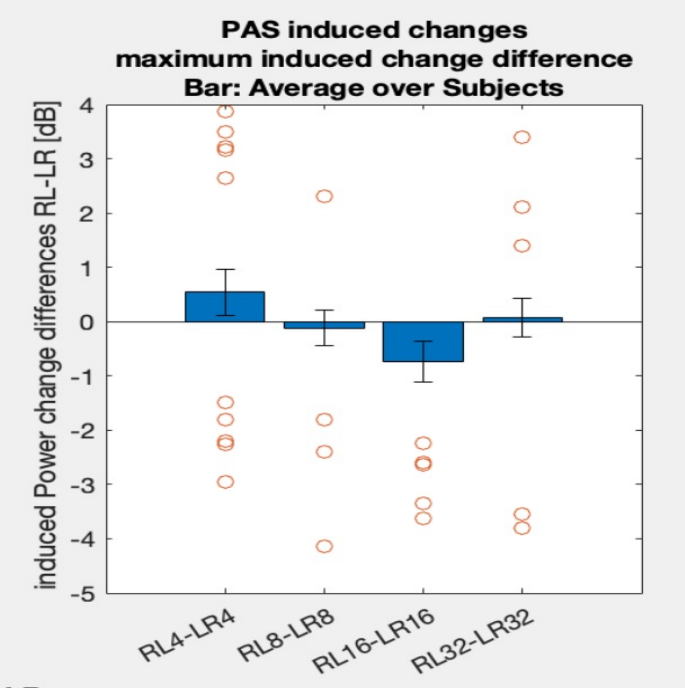
Each session: resting-state EEG → PAS stimulation (one condition) → resting-state EEG. The post-minus-pre change in alpha-band power defines the PAS-induced effect. The condition producing the largest per-subject effect defines the individual optimal IPI — our prediction target.

03 · WHY A PER-SUBJECT PREDICTOR?

Subjects respond to different stimulation parameters differently.



Average PAS-induced α-power change across conditions. Direction (RL vs LR) and IPI length both matter.



Per-subject effect (circles) at each IPI. Same stimulus, opposite effects — each subject has a preferred IPI.

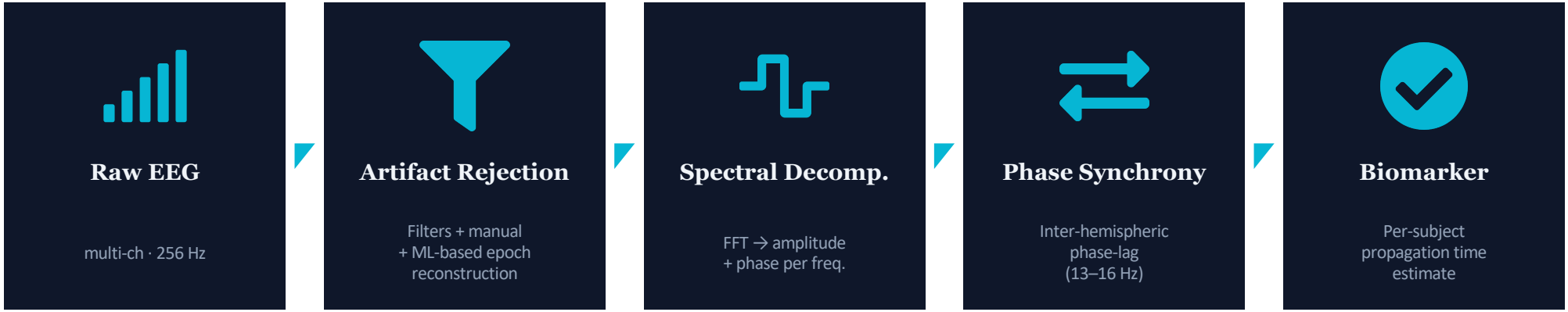
THE INSIGHT

The group-average bar hides massive individual variability.

For any given IPI, some subjects show a strong positive effect while others show a strong negative one. A fixed protocol averages the signal away.

04 · PIPELINE ARCHITECTURE

From raw EEG to a single predictive feature.



KEY INSIGHT

The pipeline is domain-agnostic: replace "EEG channels" with any multi-sensor time series (ECG leads, accelerometer axes, RF antennas) and the entire downstream flow applies. Phase-synchrony between sensors is a cross-domain feature.

05 · THE CORE METHOD

Phase-lag as a physical measure of signal propagation.

THE IDEA

Two electrodes watching the same oscillating cortical signal see it at slightly different times. The phase difference between them — at a given frequency — is proportional to how long the signal took to travel across the brain.

$$\text{prop_time} = (1000/f) \times (\Delta\phi/2\pi)$$

where $\Delta\varphi = \text{angle}(E_2) - \text{angle}(E_1)$ at frequency f

DESIGN CHOICE

Averaged across 13–16 Hz (high-alpha/low-beta). Chosen empirically: narrow band for phase stability, away from mu-rhythm artifacts.

IMPLEMENTATION (MATLAB)

```
% Phase difference across hemispheres
phaseDiff = angle(F4) - angle(F3);
phaseDiff_abs = abs(phaseDiff);

% Average across 13-16 Hz band
band = freqs > 13 & freqs < 16;
phaseDiff_band = mean(phaseDiff_abs(:,band), 2);

% Convert to propagation time (ms)
propTime = (1000 ./ freqs(band)) .* ...
           (phaseDiff_band ./ (2 * pi));

% Per-subject estimate
subjectFeature = mean(propTime, 'all');
```

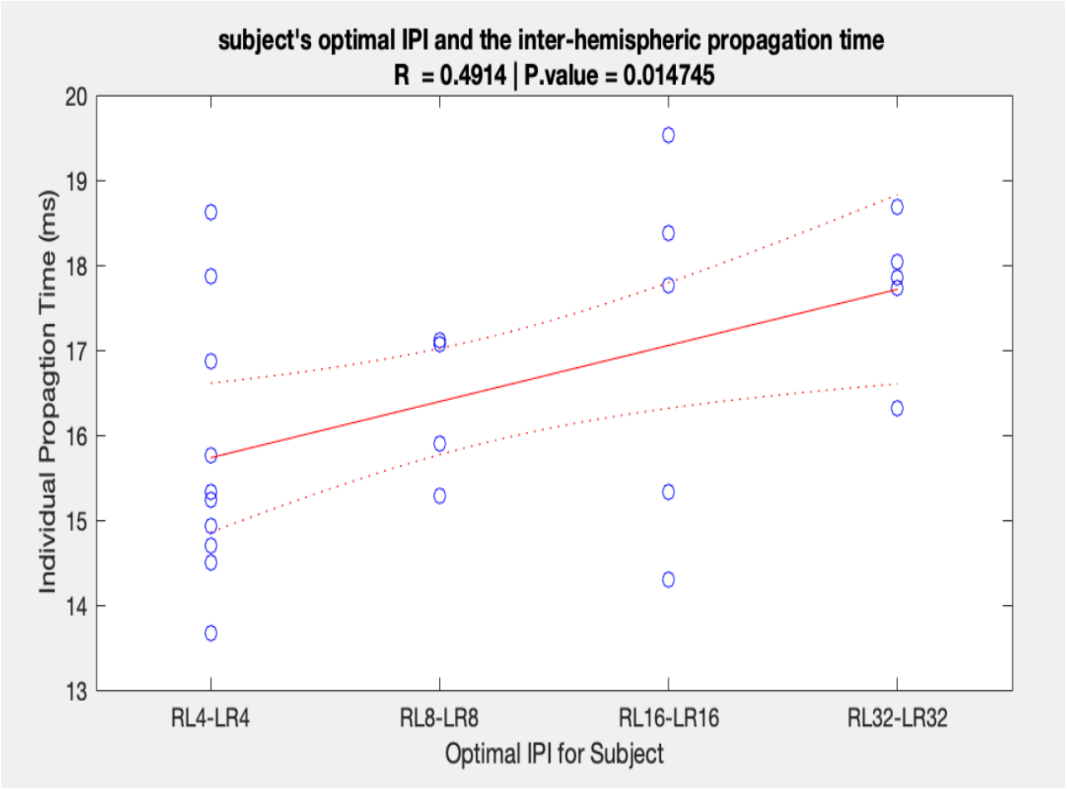
The feature predicts what we hoped.

The extracted per-subject phase-lag correlates significantly with the individually optimal IPI — subjects with longer inter-hemispheric propagation times need longer inter-pulse intervals to maximize stimulation response.

r = 0.49

p = 0.015 · linear regression, 2-tailed

Right hemisphere stimulation site (F4 electrode)



07 · VALIDATION

Not an artifact — the asymmetry is meaningful.

RIGHT HEMISPHERE (F4)

r = 0.49

p = 0.015

Significant

Phase-lag at this site tracks the true conduction delay for the stimulated circuit.

LEFT HEMISPHERE (F3)

r = 0.04

p = 0.85

Not significant

Left-hemisphere phase-lag is dominated by other dynamics — the biomarker is site-specific, as expected biologically.

Why this matters: the control direction is null, which rules out the main confound that the correlation is driven by some subject-level nuisance variable.

08 · REPLICATION

A second, related feature replicates the signal.

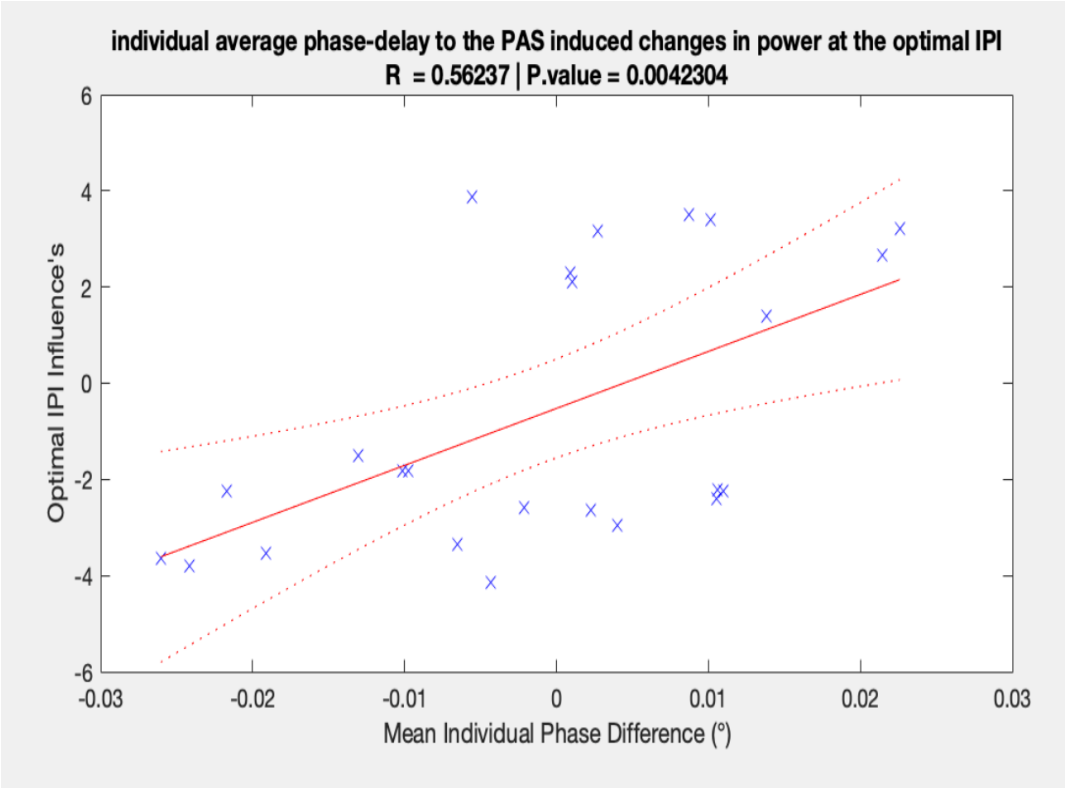
If the phase-lag story is real, a related metric — the signed mean phase difference across all 9 conditions — should also predict the magnitude of the PAS-induced effect at each subject's optimal IPI.

It does:

r = 0.56

p = 0.0042 · stronger than the primary finding

Phase-delay → induced Δpower at optimal IPI



09 · WHAT THIS ENABLES

From a fixed protocol to subject-tailored stimulation.

Pre-session EEG → IPI recommendation

A 5-minute resting-state EEG — collected before the first therapy session — is enough to extract the biomarker and select an IPI from the discrete set {4, 8, 16, 32 ms}. No additional hardware, no behavioral task.

Who is unlikely to respond

Subjects whose propagation time falls outside the range where any discrete IPI provides a good match are flagged as likely non-responders — information a clinician can act on before committing to a multi-week course.

A motivated next study

An observational correlation is not a clinical result. The natural follow-up is a randomized controlled trial with stimulation individually adjusted from the biomarker, versus the current fixed protocol.

Findings contributed to internal R&D discussion at Brainsway's Deep-TMS clinical trial program.

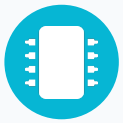
Same pipeline, other domains.

The techniques used here — multi-sensor spectral decomposition, inter-channel phase-synchrony, per-subject feature extraction — generalize directly to any multi-channel time-series domain:



Biosignal

ECG arrhythmia
sleep staging
motor imagery BCI



IoT & Sensors

bearing fault detection
structural health
accelerometer arrays



RF & Comms

MIMO channel analysis
direction-of-arrival
radar signatures



Acoustic

source localization
drone detection
industrial audio

The domain is neuroscience. The methodology is signal processing.

11 · STACK & CONTACT

Built with.

SIGNAL PROCESSING

MATLAB · FFT · EEGLAB

STATISTICAL ANALYSIS

linear models · correlation · bootstrap

DATA ENGINEERING

multi-session time series · artifact pipelines

DELIVERABLES

conference poster · internal R&D findings

Yarden Viktor Dejorno

ML Engineer · Time-Series & Signal Processing

hrsi56@gmail.com

linkedin.com/in/yvdejorno

github.com/hrsi56