

Transdiagnostic interoceptive profiling from routine EEG-ECG recordings

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INTRODUCTION

Interoception — the sensing, interpretation, and integration of internal body signals — is fundamental to emotional regulation, and self-awareness.¹ These processes are disrupted across psychiatric disorders.

Routine EEG-ECG recordings offer complementary interoceptive windows:

- **heart rate variability (HRV)**, indexing autonomic regulatory flexibility²
- **heartbeat-evoked potential (HEP)**, an ERP reflecting cortical processing of each heartbeat³
- **phase-amplitude coupling (PAC)**, cardiac modulation of EEG band-power⁴

These measures remain largely unexplored in large, clinical samples.

Aim : Explore whether these measures capture disorder-specific interoceptive profiles, in a routine clinical setting.

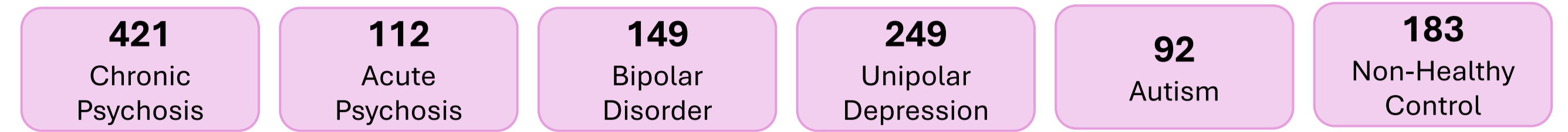
Hypothesis: We expected interoceptive dysregulation to be **most pronounced in psychotic disorders**, and that position along the psychosis-autism neurodevelopmental continuum would modulate interoceptive profiles in a graded fashion.

EEG : Electroencephalogram, ECG: Electrocardiogram

COHORT

Retrospective analysis of **routine clinical EEGs** (2019-2024) from the GHU Paris Psychiatry and Neurosciences data warehouse.

Subjects with a **single diagnosis, excluding neurodevelopmental co-morbidities**, and adequate recording quality were retained. A total of **1201 subjects** were retained for analysis :



Age: 37.4 ± 18.1 years (range 10.0–90.0)
Sex: 43.9% female, 56.1% male

EEG & ECG recordings :

- **19-channel EEG** (Micromed®, 10–20 system, 256 Hz, impedance < 5 kΩ) with simultaneous single-lead ECG.
- Recordings (~20 min) included: **rest sequences**, hyperpnea and visual light stimulation. We only selected **continuous rest segments** that were >60s. (rest duration: 4.30 ± 2.52 min)
- **Medication** : olanzapine, fluoxetine and X equivalents were computed at the time of EEG recording

METHODS

Preprocessing

EEG

Band-pass 0.5–45 Hz → RANSAC bad channel detection → Spherical spline interpolation → Average re-reference → ICA + ICLabel → Cardiac IC rejection

ECG

High-pass filter 1 Hz → R-peak detection (find_ecg_events) → RR interval filtering (300–2000 ms)

Feature extraction

HRV

Metric : **RMSSD** - Root Mean Square of Successive Differences
→ Index of vagally-mediated autonomic tone

HEP

- R-peak locked epochs **-250 to +600 ms** → AutoReject artifact removal.
- Fronto-central **ROI**: Fp1, Fp2, Fz, F3, F4, F7, F8, C3, Cz, C4.
- Metrics: **peak amplitude** and **peak latency** (300–600 ms window).

PAC

- HF-HRV phase via subject-specific narrow-band FIR (individual HF peak, 0.15–0.4 Hz).
- **Modulation Index** computed against EEG **alpha** amplitude envelope.
- Z-scored against 200 time-shift surrogates.

Statistical Analysis

Primary : ANCOVA with diagnostic group as main factor, covarying for age, sex, and medication load (olanzapine, diazepam, fluoxetine equivalents).

$$\text{Feature} = \text{Group} + \text{Age} + \text{Sex} + \text{Medication} + \text{RMSSD}$$

Secondary : ANCOVA repeated with **RMSSD** added as an additional covariate, to control for cardiac autonomic tone.

$$\text{Feature} = \text{Group} + \text{Age} + \text{Sex} + \text{Medication} + \text{RMSSD}$$

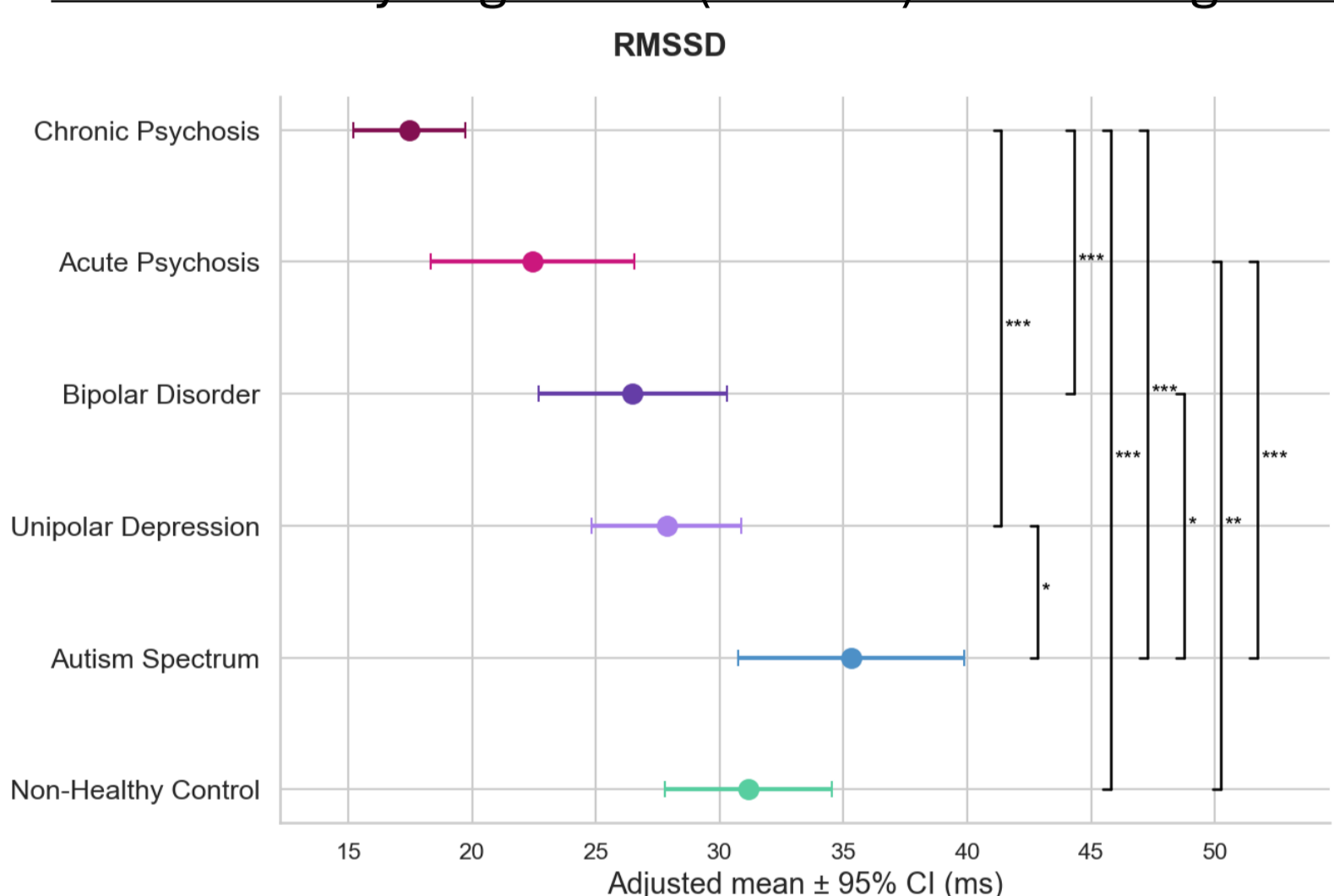
Pairwise comparisons between diagnostic groups via estimated marginal means, computed at the mean of all covariates.

FDR correction (Benjamini–Hochberg) applied across all outcomes.

Significance threshold $\alpha = 0.05$.

RESULTS

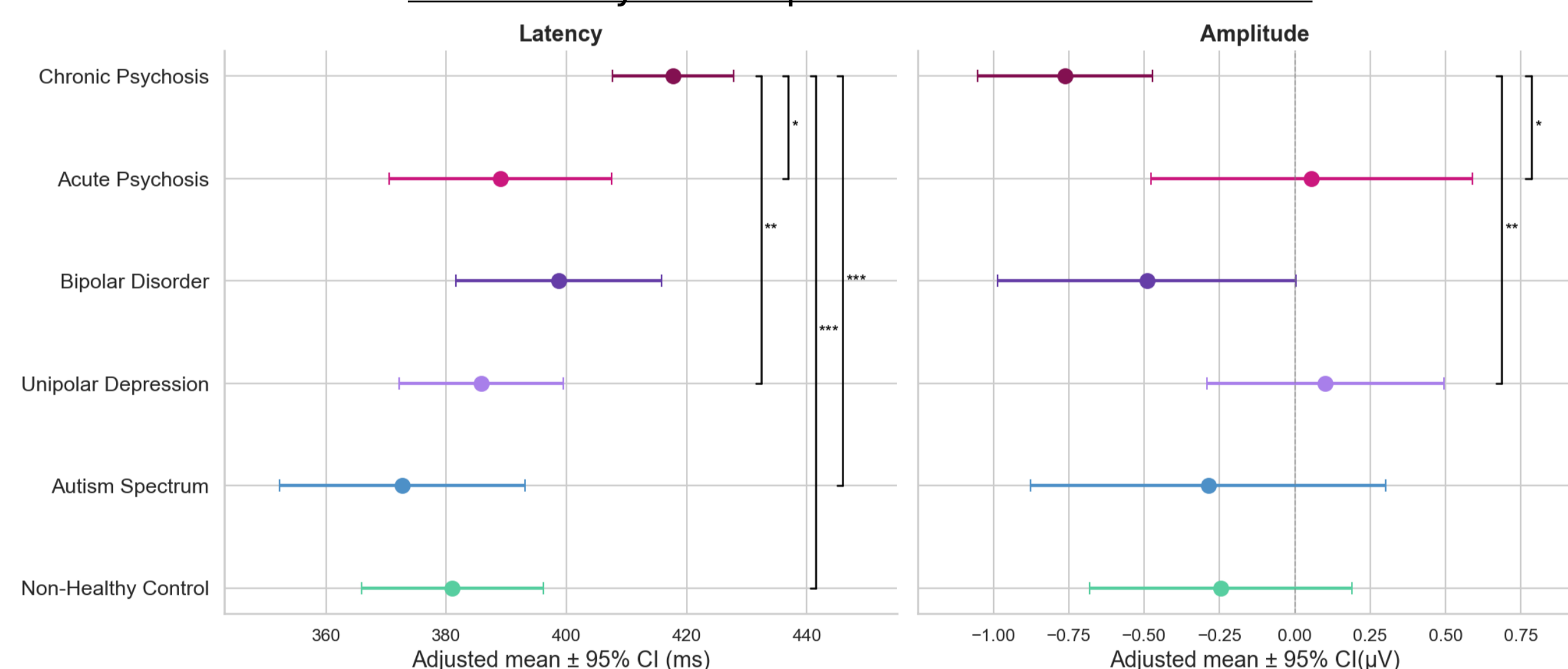
Autonomic dysregulation (RMSSD) across diagnoses



RMSSD varied significantly with diagnosis.

- **Chronic psychosis** had significantly lower RMSSD than almost all other groups (~15 ms).
- **Acute psychosis** was also **reduced** relative to non-healthy controls and autism.
- **Autism** and **Non-Healthy Control** have the highest RMSSD – and no difference between each other

HEP latency and amplitude in Frontocentral ROI



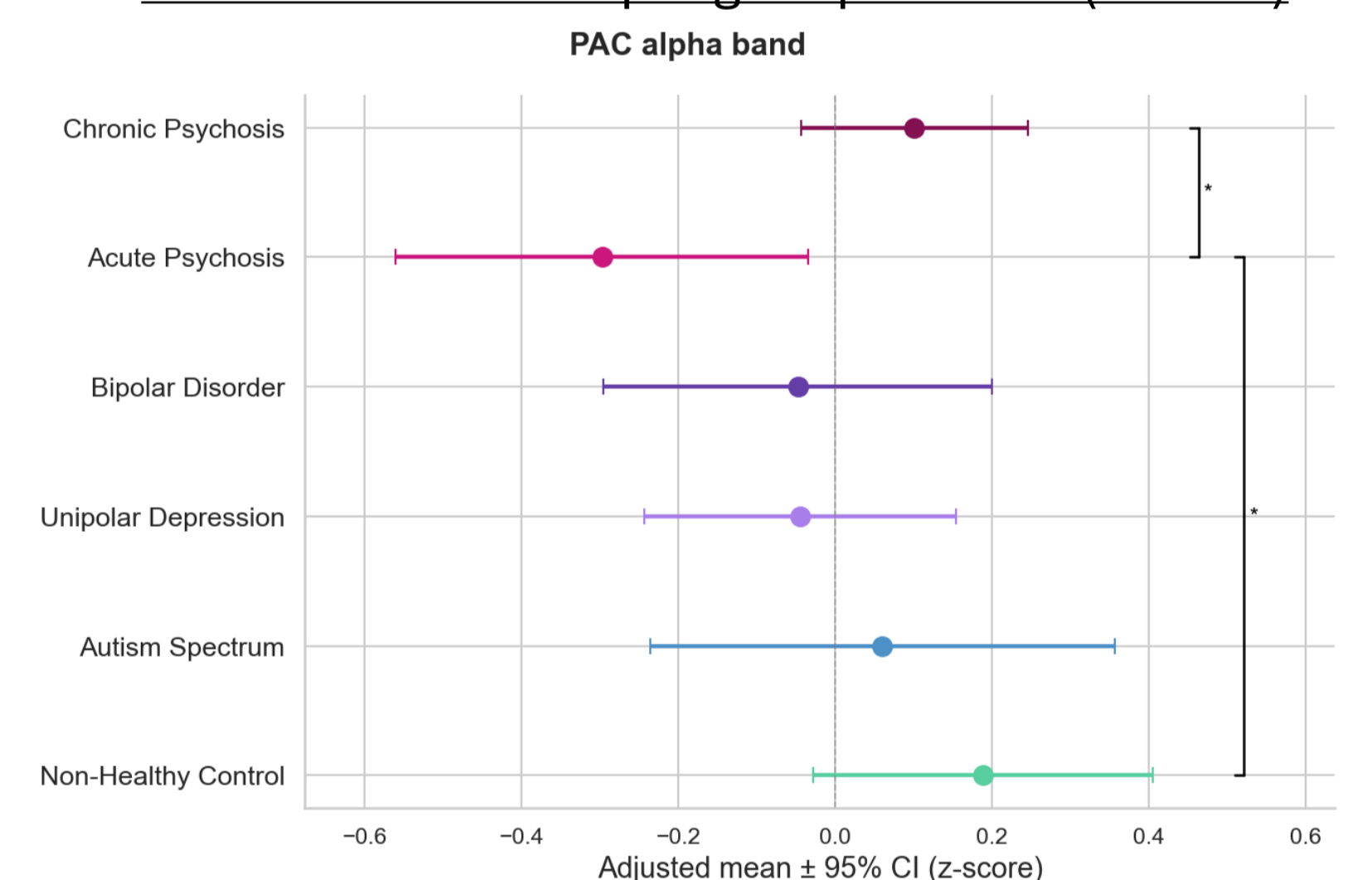
Peak latency differed significantly across groups ($p_{\text{fdr}} = .006$).

- **Chronic psychosis**: longest HEP latency (~420 ms); significantly delayed vs non-healthy controls, autism, unipolar depression, and acute psychosis.
→ inverted pattern relative to RMSSD

Peak amplitude differed across groups ($p_{\text{fdr}} = .020$).

- **Chronic psychosis**: most negative amplitude (~-0.75 µV), significantly lower than unipolar depression and acute psychosis
→ suggests hyperactive cortical representation of the cardiac signal.

Cardiac-neural coupling – alpha band (8-13Hz)



Phase-amplitude coupling between HF-HRV phase and EEG **alpha band** amplitude showed that:

- **Acute psychosis** had a significantly lower alpha zMI than both non-healthy controls and chronic psychosis.
→ selective reduction during an *acute* (but not *chronic*) phase suggests a state-dependent disruption rather than a fixed trait.

$p < 0.05$: *; $p < 0.01$: **; $p < 0.001$: ***

KEY FINDING – RMSSD correction

When RMSSD was added as a covariate (so that cardiac regulatory capacity is accounted for), the cortical interoceptive signal (HEP and PAC) is no longer different groups.
→ suggesting that the HEP differences are substantially affected by autonomic tone.

CONCLUSION & PROSPECTS

- **Autonomic tone is the primary driver** of transdiagnostic interoceptive differences: chronic psychosis shows the lowest RMSSD, and when statistically controlled, HEP latency and amplitude group differences disappear
- **Chronic psychosis shows both delayed and hyperactive cortical heartbeat processing**, suggesting a dual failure in interoceptive timing and signal weighting.
→ HEP group differences should not be interpreted as purely cortical without accounting for autonomic tone.

- **Increase minimum resting segment length from 60 to 180 seconds** to improve signal stability and reliability of HRV and PAC estimates.
- **Examine the influence of somatic co-morbidities** (cardiovascular, respiratory and digestive conditions)
- **Move beyond diagnostic categories** using data-driven clustering approaches to identify transdiagnostic interoceptive profiles

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(2) Oliveira M, da-Silva M, Carvalho L, et al. Interplay Between Cortical and Neurocardiac Interoceptive Processes and its Association with Self-Reported Interoceptive Sensibility. *Brain Topogr.* 2025;38(4):48. doi:10.1007/s10548-025-01122-1

(3) Koreki A, Ogyu K, Miyazaki T, et al. Aberrant heartbeat-evoked potential in schizophrenia. *Prog Neuropsychopharmacol Biol Psychiatry.* 2024;132:110969. doi:10.1016/j.pnpbp.2024.110969

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