Parametric Models of Phase-Amplitude Coupling in Neural Time Series

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Abstract

- In neuroscience, *phase-amplitude coupling* (PAC) refers to the interaction between the phase of a slow neural oscillation and the amplitude of high frequencies, within the same signal or across two signals.
- To model PAC, we use *new* parametric *driven auto-regressive* (DAR) models. These generative statistical models provide a non-linear spectral estimation of the signal, and are able to capture the time-varying behavior of PAC.
- We show that they are more robust to detect PAC in short signals than two state-of-the-art empirical PAC metrics.

Phase Amplitude Coupling (PAC)

Coupling between:

- Phase of a slow oscillation
- Amplitude of high frequencies

Driven Auto-Regressive (DAR) models

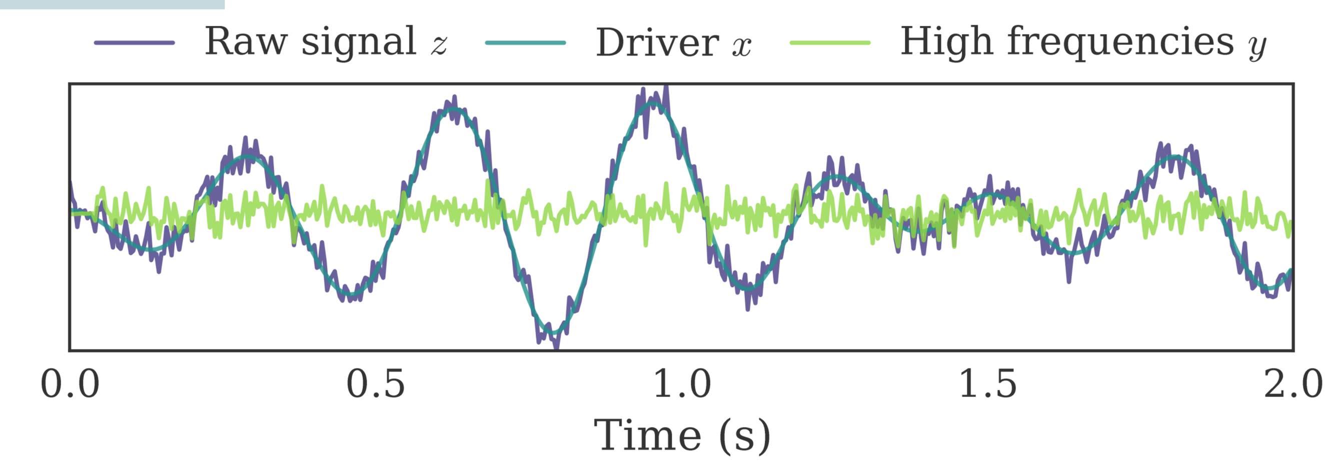
- AR model $$y(t) + \sum_{i=1}^{p} a_i y(t-i) = \varepsilon(t)$$
- DAR model $$a_i(t) = \sum_{j=0}^{m} a_{ij} x(t)^j, \quad \log(\sigma(t)) = \sum_{j=0}^{m} b_j x(t)^j$$
- Maximum Likelihood Estimate :
  - Linear system for the AR coefficients a_{ij}
  - Newton-Raphson for the gain coefficients b_j
- Likelihood $$L = \prod_{t=p+1}^{T} \frac{1}{\sqrt{2\pi\sigma(t)^2}} \exp\left(-\frac{\varepsilon(t)^2}{2\sigma(t)^2}\right)$$
- Power spectral density $$S_y(x_0)(f) = \left|\sum_{i=0}^{p} \frac{a_i(x_0)}{\sigma(x_0)} e^{-j2\pi f i}\right|^{-2}$$

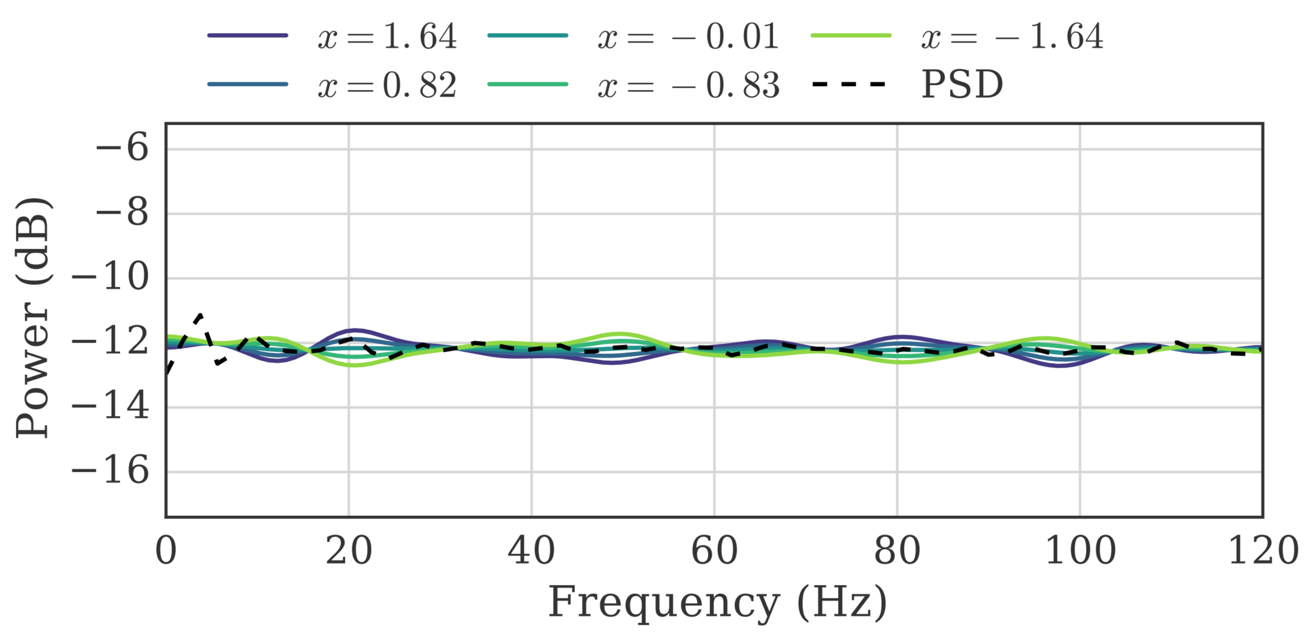
Signal and driver

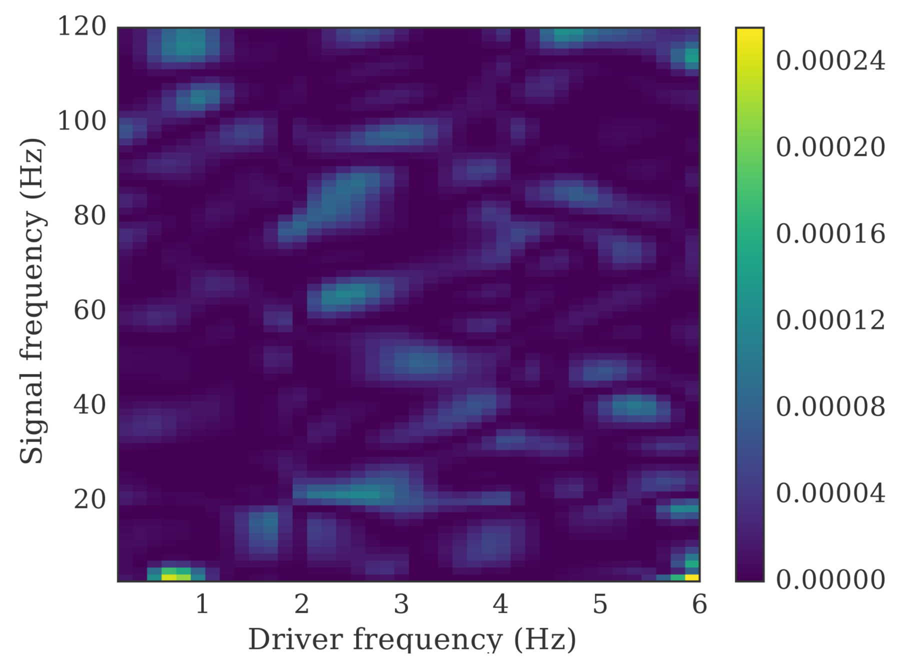
Power spectral density

Comodulogram

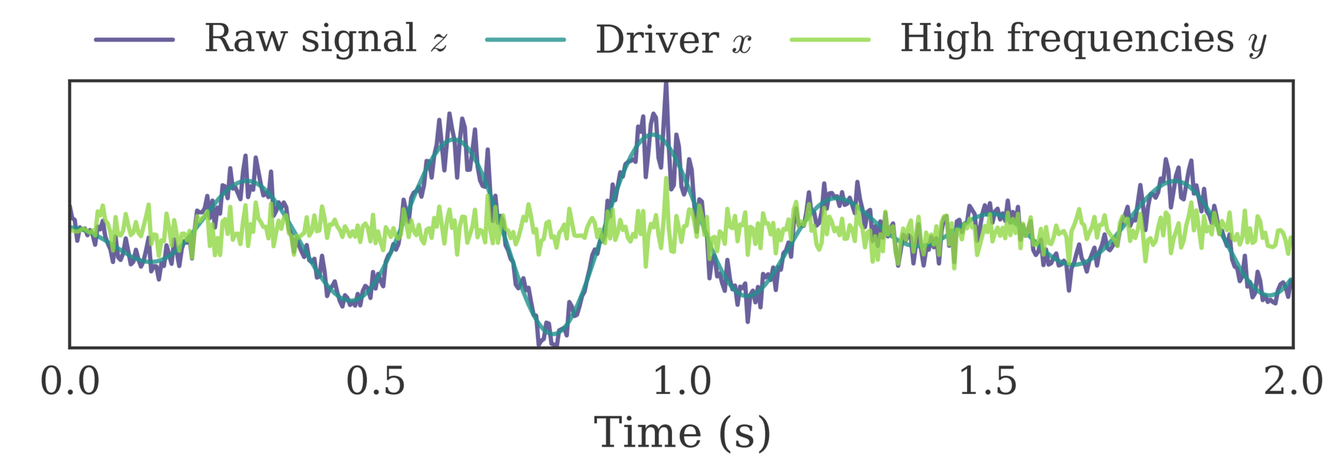
No PAC

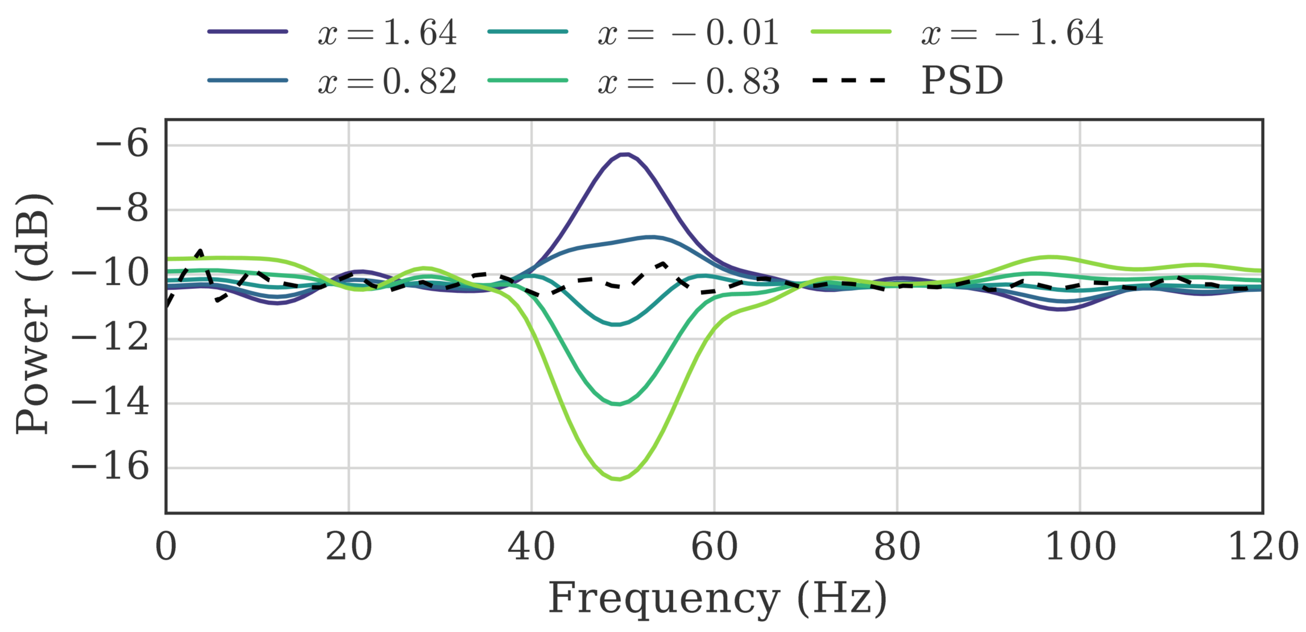


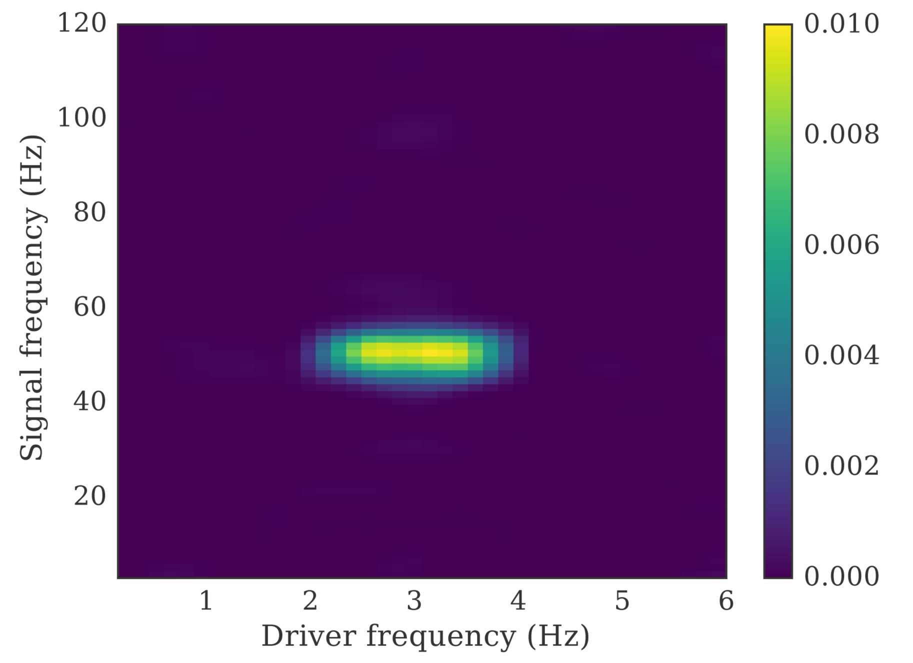




PAC







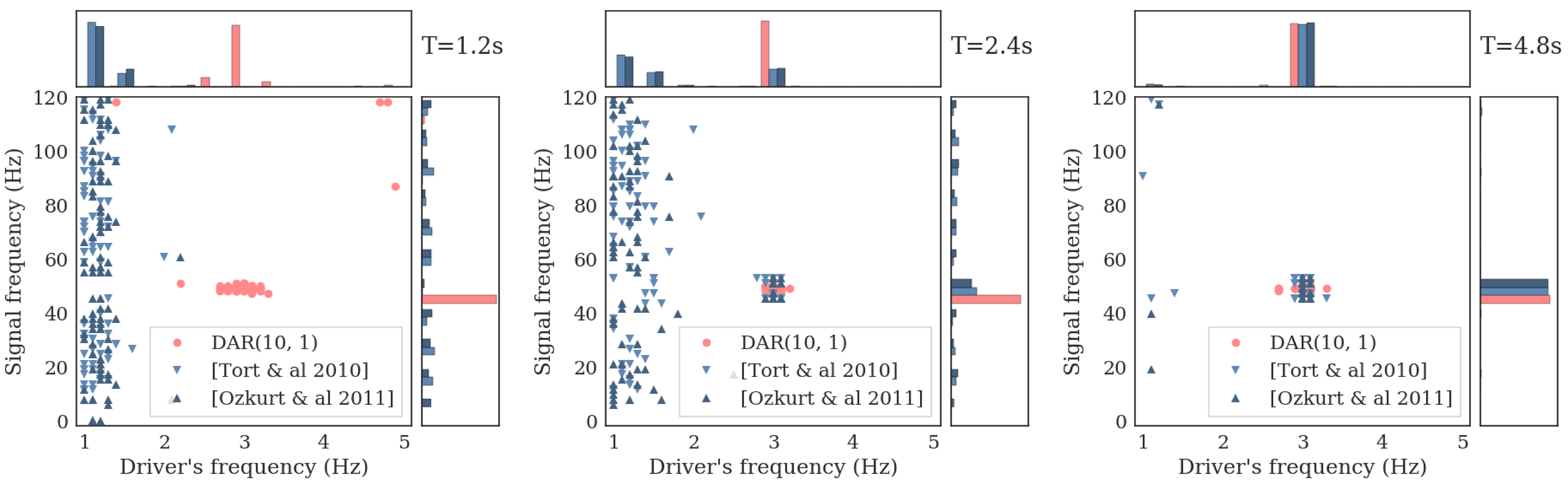
Robustness to short signals

Simulation:

- 100 signals of length 1.2s, 2.4s and 4.8s with a PAC between 3 Hz and 50 Hz
- For each signal, we select the frequencies with the maximum measured PAC

Results:

- DAR models are able to select the correct frequencies even with short signals



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