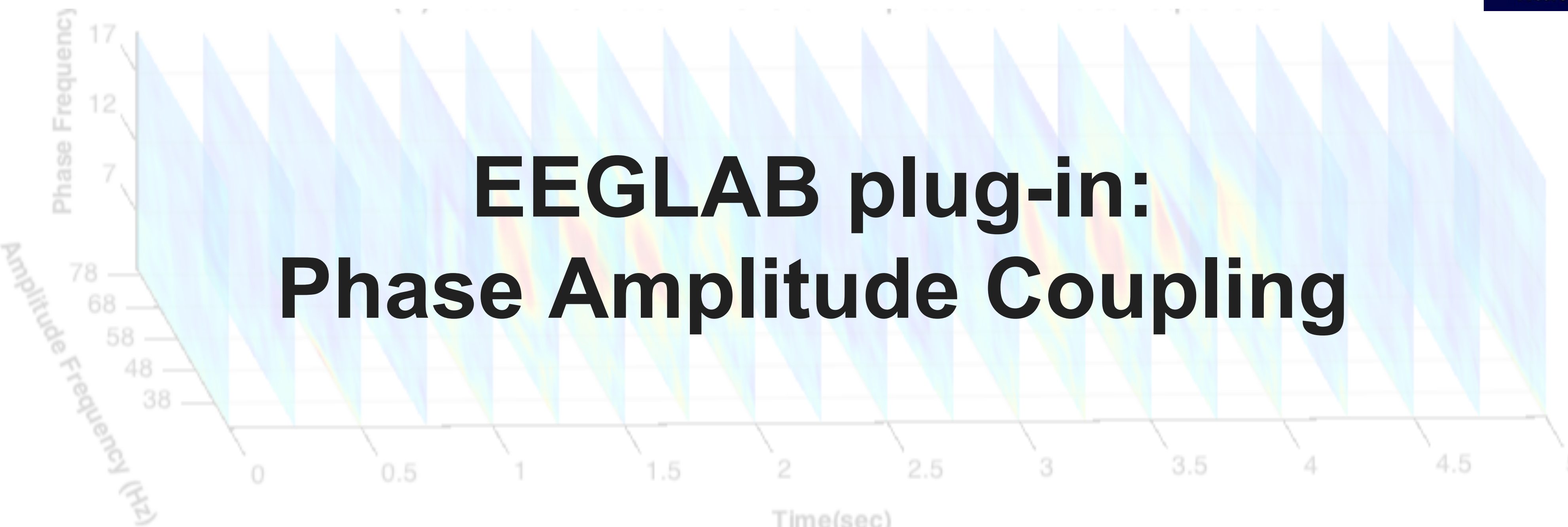


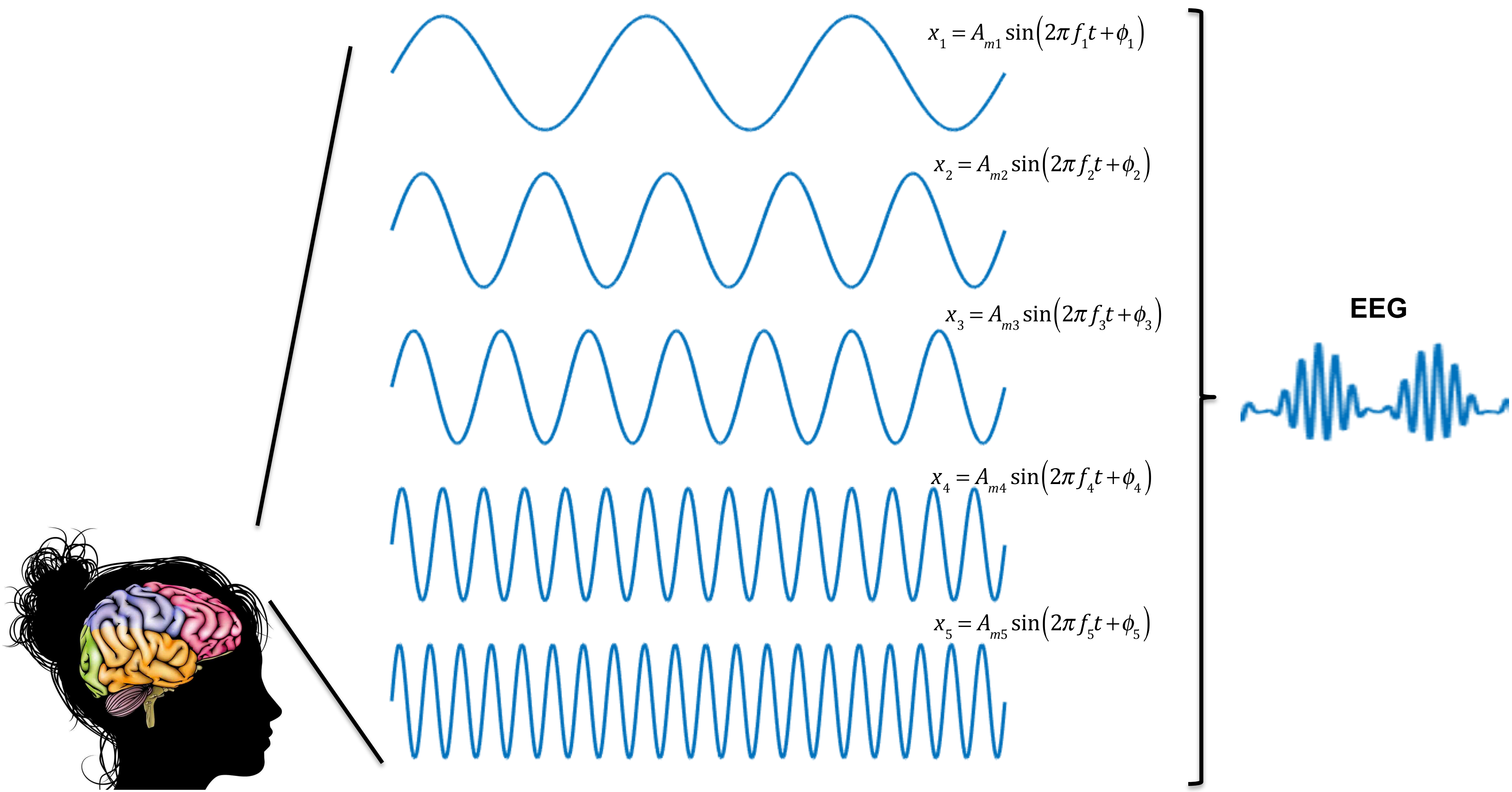
EEGLAB plug-in:
Phase Amplitude Coupling

Ramon Martinez-Cancino **Joseph Heng**

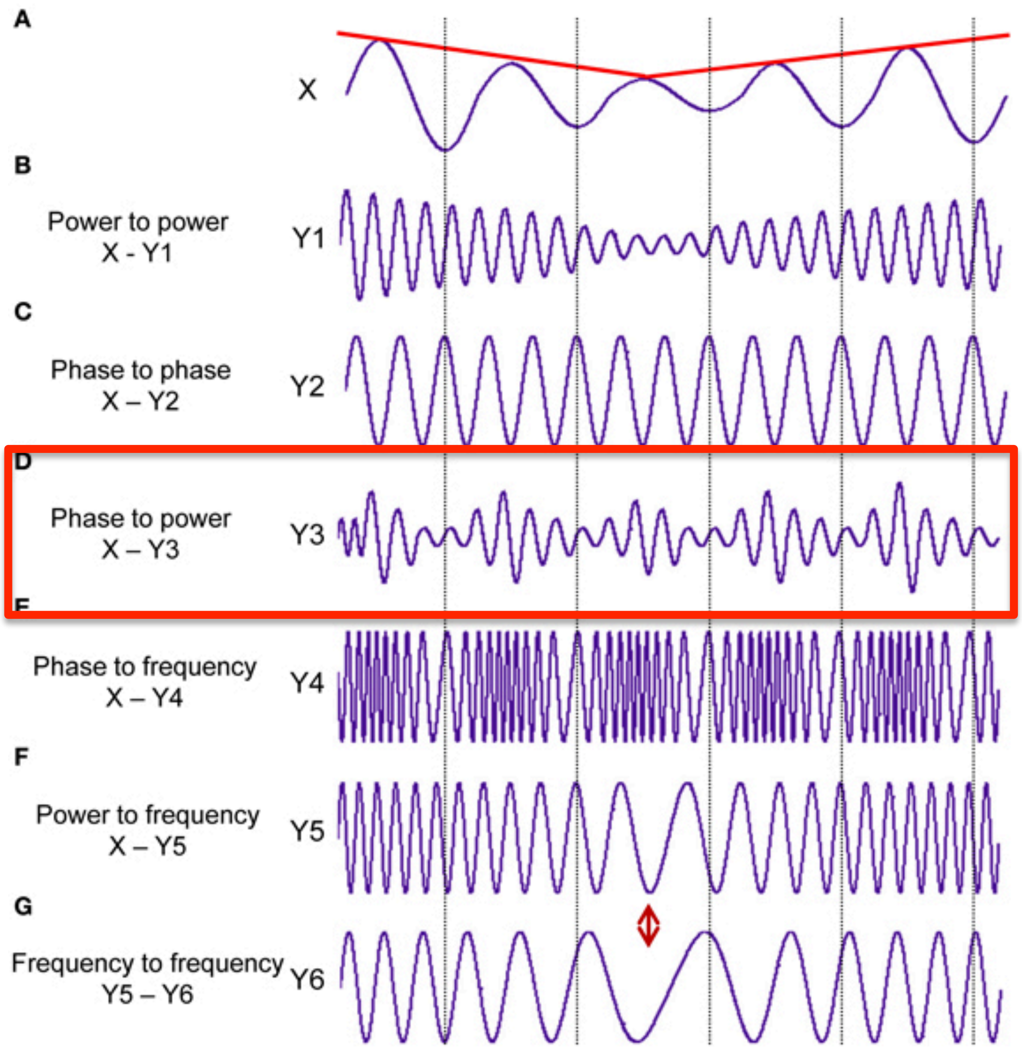
EEGLAB workshop 2016, UCSD, La Jolla

Swartz Center for Computational Neuroscience

Cross Frequency Coupling



Different Types of Cross-Frequency Coupling



Jirsa and Muller, 2013

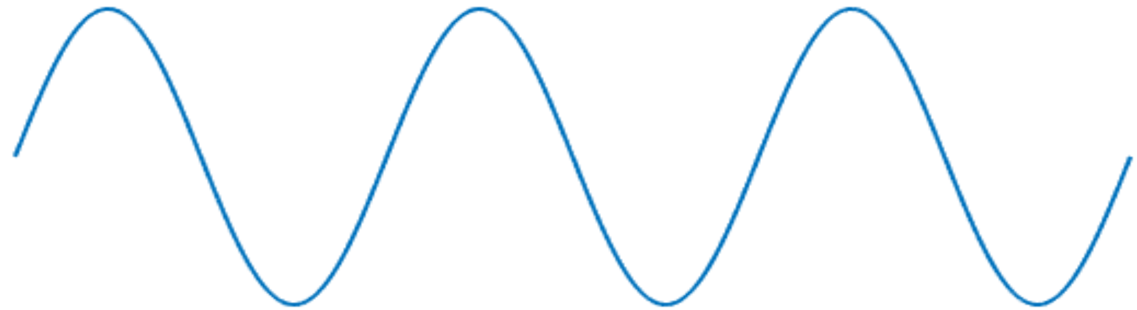
Found both in animals and humans in the *entorhinal* and *prefrontal cortices*, in the *hippocampus*, and distributed cortical areas

(Mormann et al., 2005; Cohen, 2008; Osipova et al., 2008; Tort et al., 2008, 2009, 2010; Cohen et al., 2009a,b; Colgin et al., 2009; Axmacher et al., 2010a,b; Voytek et al., 2010)

Amplitude Modulation Fundamentals

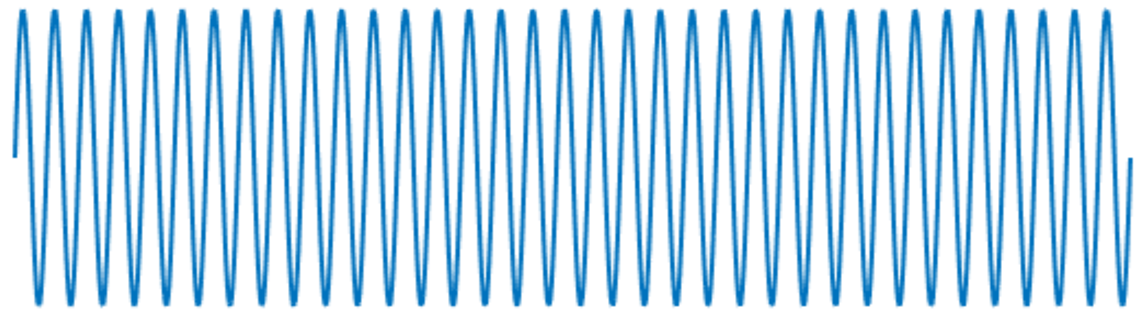
Modulator

$$v_{\mathrm{mod}} = V_{\mathrm{mod}} \sin\left(2\pi f_{\mathrm{mod}} t\right)$$



Carrier

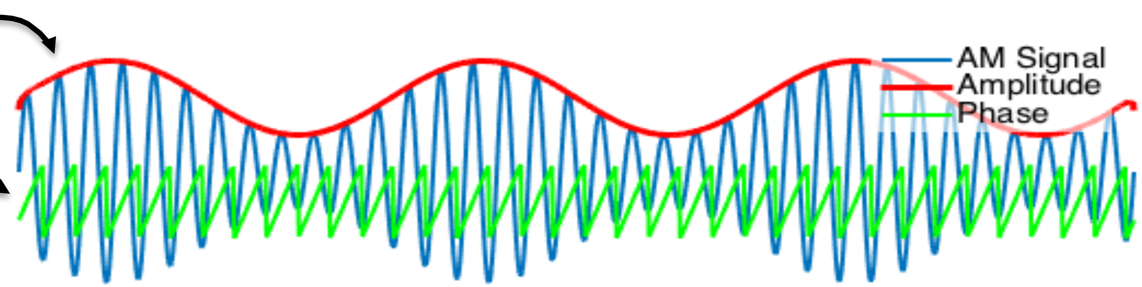
$$v_{carr} = V_{carr} \sin\left(2\pi f_{carr} t\right)$$



AM Signal

$abs\left(hilbert\left(v_{AM}\right)\right)$

$angle\left(hilbert\left(v_{AM}\right)\right)$



$$v_{AM} = V_{carr} \sin\left(2\pi f_{carr} t\right) + \left[V_{\mathrm{mod}} \sin\left(2\pi f_{\mathrm{mod}} t\right)\right] \sin\left(2\pi f_{carr} t\right)$$

Envelope and instantaneous phase

$$s(t) = s_m(t)e^{i\phi(t)}$$

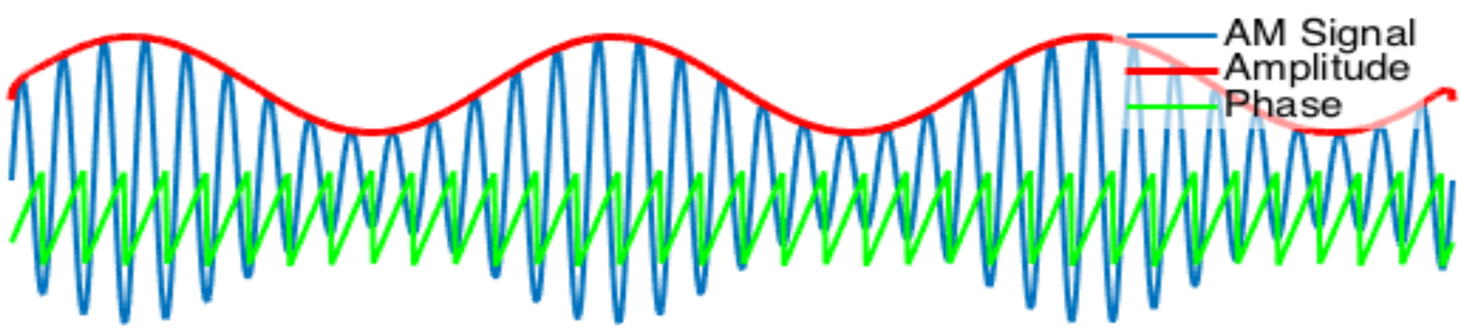
By mean of the ***Hilbert transform*** a signal can be expressed as its analytic signal in terms of its time-variant magnitude and phase

$$s_m(t) = |s(t)|$$

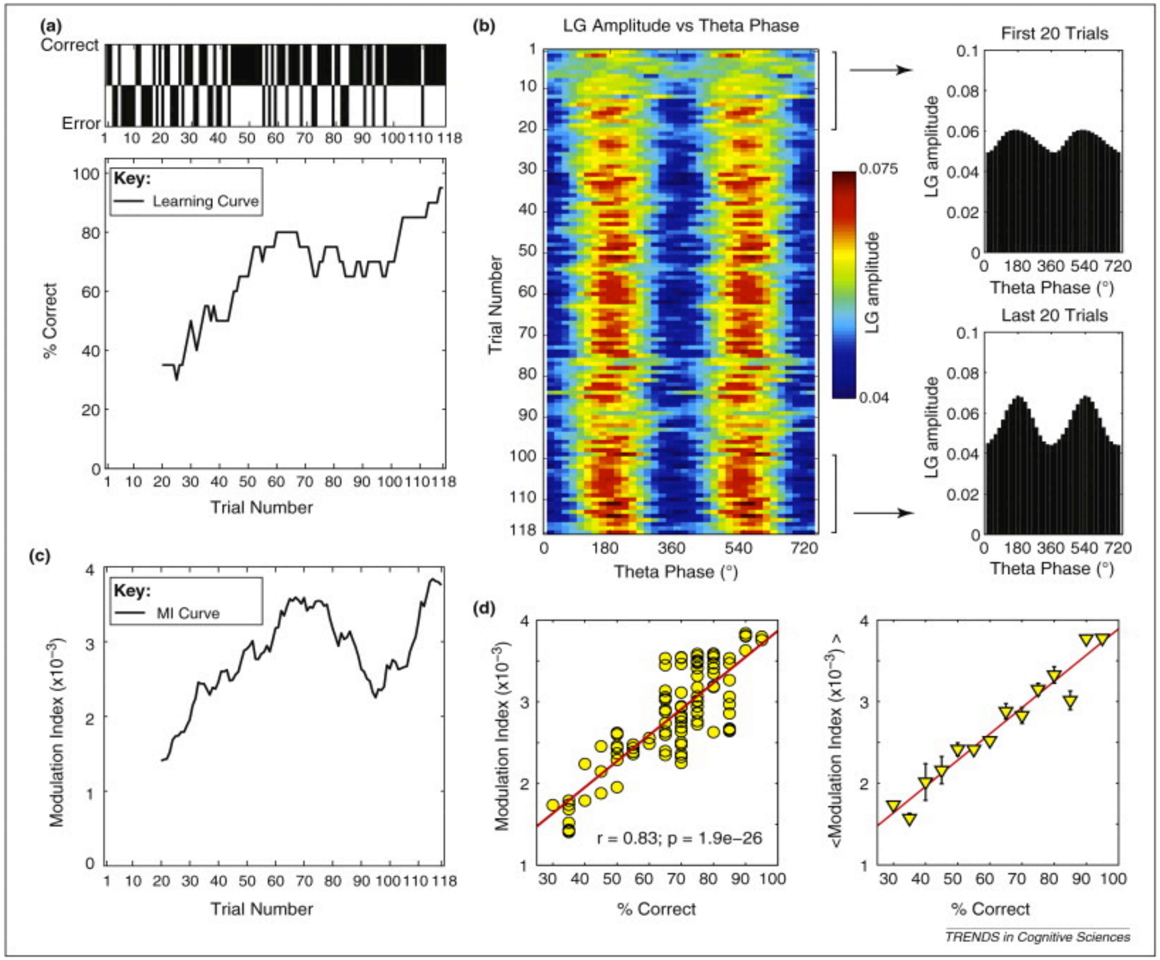
Instantaneous amplitude or the envelope

$$\phi(t) = \arg[s(t)]$$

Instantaneous phase.



PAC in Neurosciences



Tort et al, 2009

Hippocampal theta–gamma CFC correlates with learning and task performance. Theta modulation of low gamma (LG) amplitude in the CA3 region during context exploration increases with learning.

(a) Behavioral profile of a representative rat during learning of the task. The animal's performance (correct, black bar up; error, black bar down) in each trial of the session (upper) and the associated learning curve computed using a sliding window of 20 trials (lower) are shown.

(b) Pseudocolor scale representation of the mean CA3 LG amplitude as a function of the theta phase for each trial in the session (left). The mean LG amplitude per theta phase averaged over the first and last 20 trials is also shown (right).

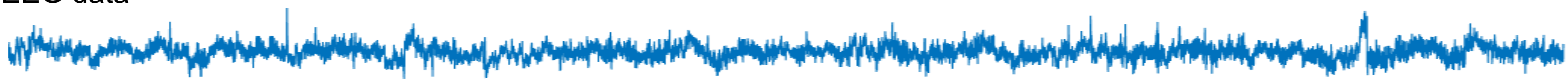
(c) CFC modulation index (MI) curve computed using a 20-trial sliding window.

(d) Linear correlation between theta-LG coupling strength and task performance. The correlation between the MI and learning curves (left) and the average MI value over each mean performance percentage (right) are shown.

Strength of the phase-amplitude coupling may change depending on cognitive demands !!!

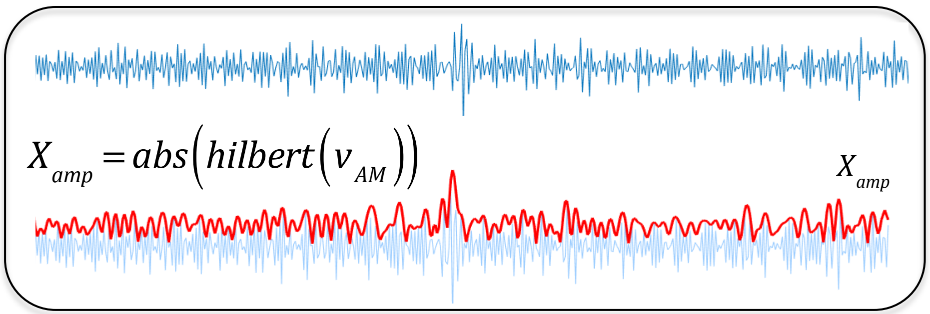
Computing PAC

EEG data

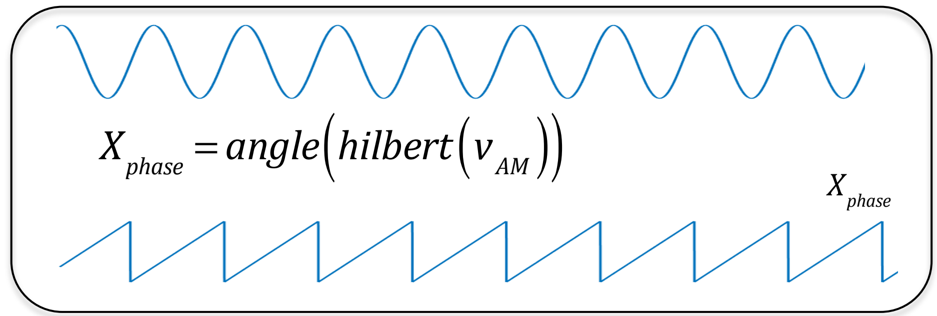


High frequency band (30-50Hz) | *Low frequency band (5-12Hz)*

Band-pass Filter



$$X_{amp} = abs\left(hilbert\left(v_{AM}\right)\right)$$



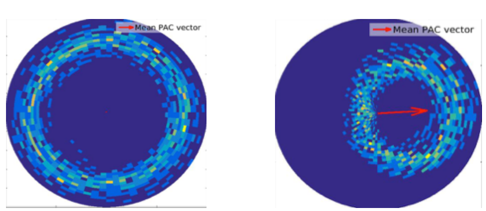
$$X_{phase} = angle\left(hilbert\left(v_{AM}\right)\right)$$

Mean Vector Length

Canolty et al. 2006

- Create composite vectors
- Check for length of the mean vector

$$PAC = \left| X_{amp} e^{iX_{phase}} \right|$$



No Coupling   Coupling

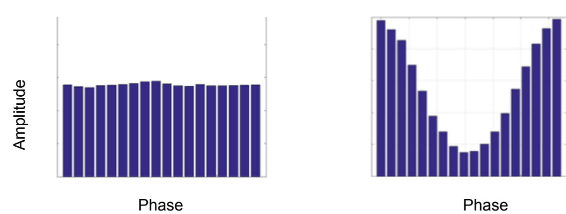
Kullback-Leibler Modulation Index

Tort et al, 2010

$$P(j) = \frac{\langle A_{f_A} \rangle \phi_{f_p}(j)}{\sum_{k=1}^{N} \langle A_{f_A} \rangle \phi_{f_p}(k)}$$

$$MI = \frac{D_{KL}(P,U)}{\log N}$$

Compute the Kullback-Leibler distance to a uniform distribution



Coupling   No Coupling

GLM Measure

Penny et al. 2008

Regress *sin* and *cos* of the phase from the amplitude and use the explained variance as an index of correlation

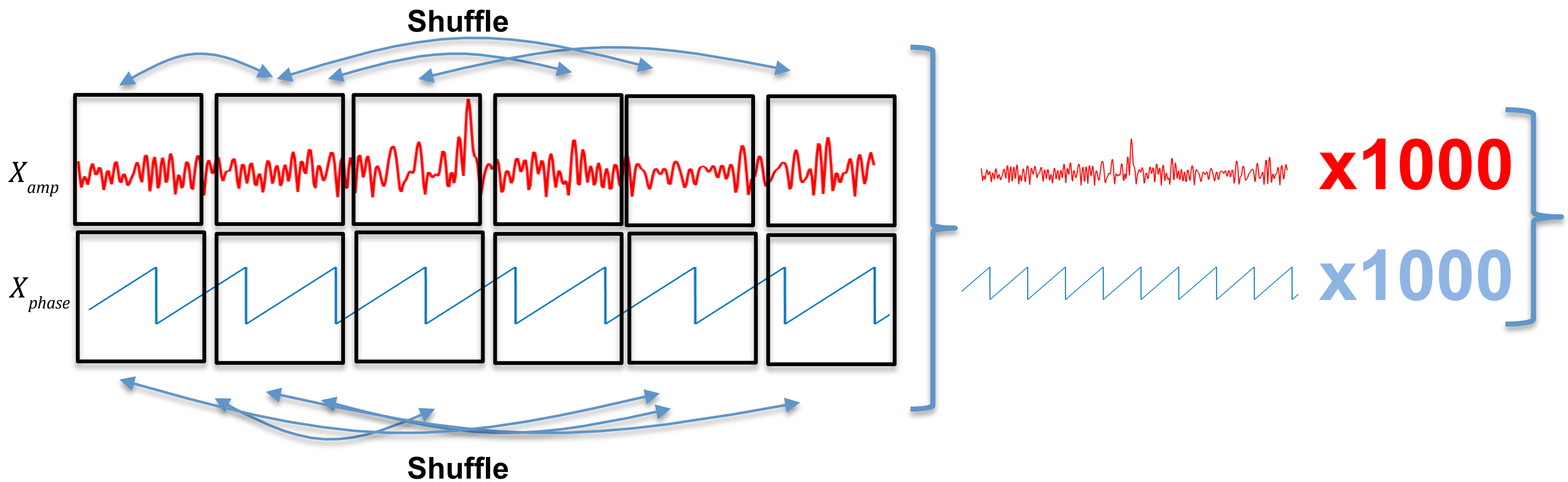
$$X_{amp} = X_{amp}\beta + e$$

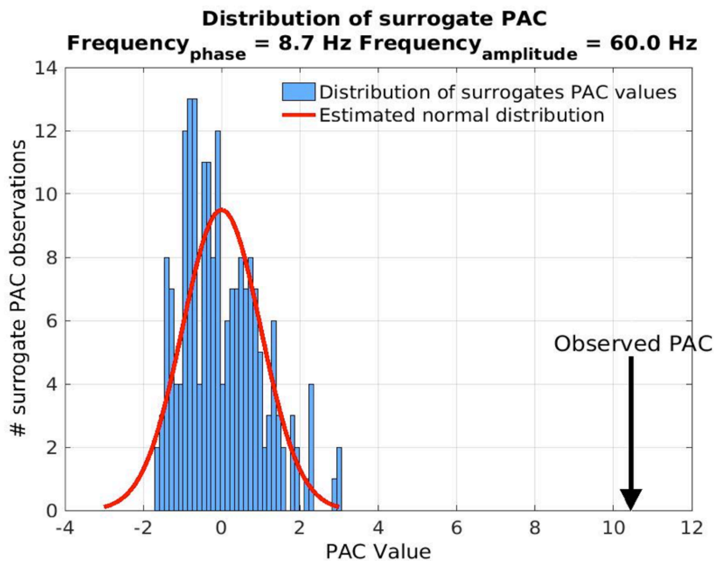
$$X_{amp} = \beta_1 \sin\left(X_{phase}\right) + \beta_2\left(X_{phase}\right)$$

$$r^2_{GLM} = \frac{SS_{X_{amp}} - SS_e}{SS_{X_{amp}}}$$

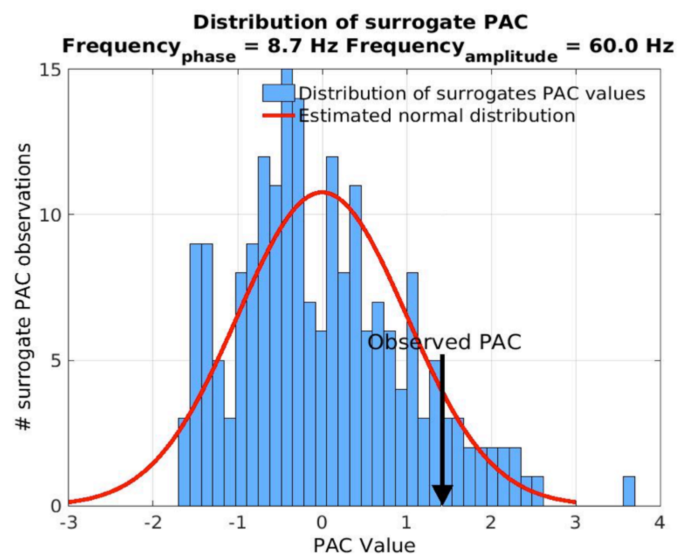
Computing PAC statistics

Generating surrogate signals for X_{amp} and X_{phase}





Coupling



No Coupling

Why several methods ?

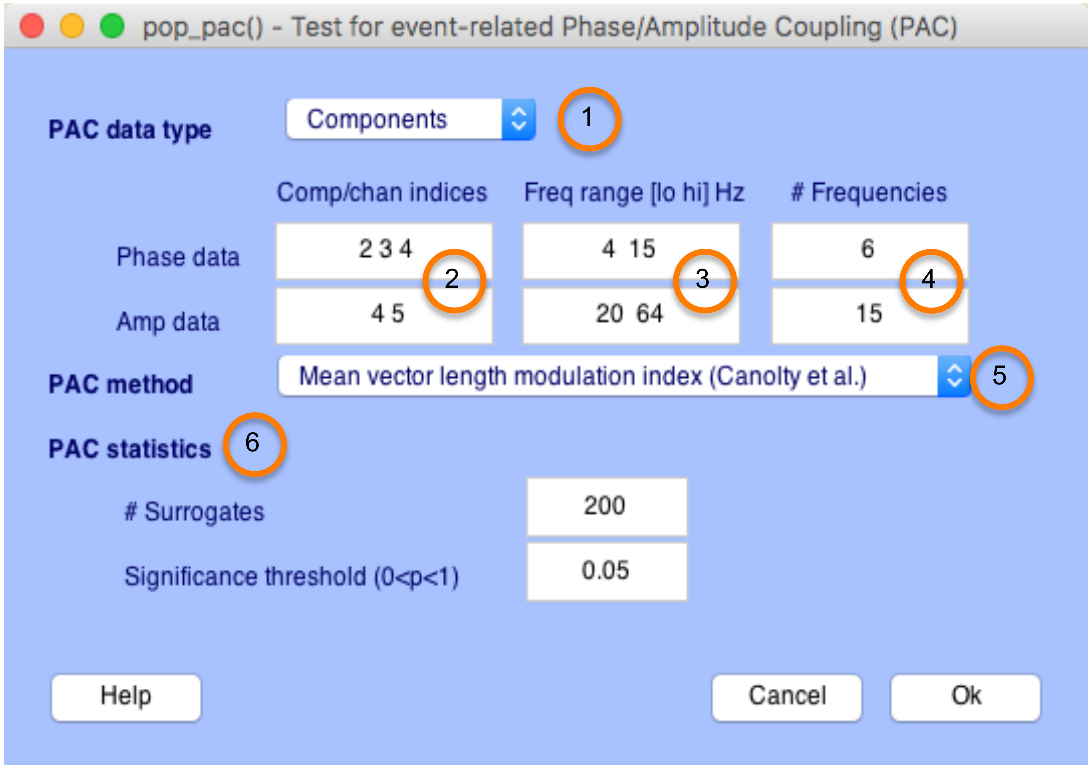
Summary of characteristics of the phase-amplitude coupling measures studied

Phase-Amplitude Coupling Measure	Tolerance to Noise	Amplitude Independent	Sensitivity to Multimodality	Sensitivity to Modulation Width
Modulation index	Good	Yes	Good	Good
Mean vector length	Good	No	Restricted	Reasonable
GLM measure	Low	No*	Restricted	Low

* Under the presence of noise.

From Tort et al. 2010

EEGLAB Plug-in: Phase Amplitude Coupling



1 - Type of data to use in the computation. {Components, Channels}

2 - Indices of channels/components to use.

3 - Frequency range of the bands to compute PAC. [fmin fmax]

4 - Number of frequencies to use from the range.

5 - PAC methods:
- Mean vector length modulation index (Canolty et al, 2006)
- Kullback-Leibler modulation index (Tort et al, 2010)
- Sin/Cos regression (GLM). (Penny et al, 2008)

6 - PAC stats parameters:
- Number of surrogates
- Significance threshold

EEGLAB plug-in: Phase Amplitude Coupling